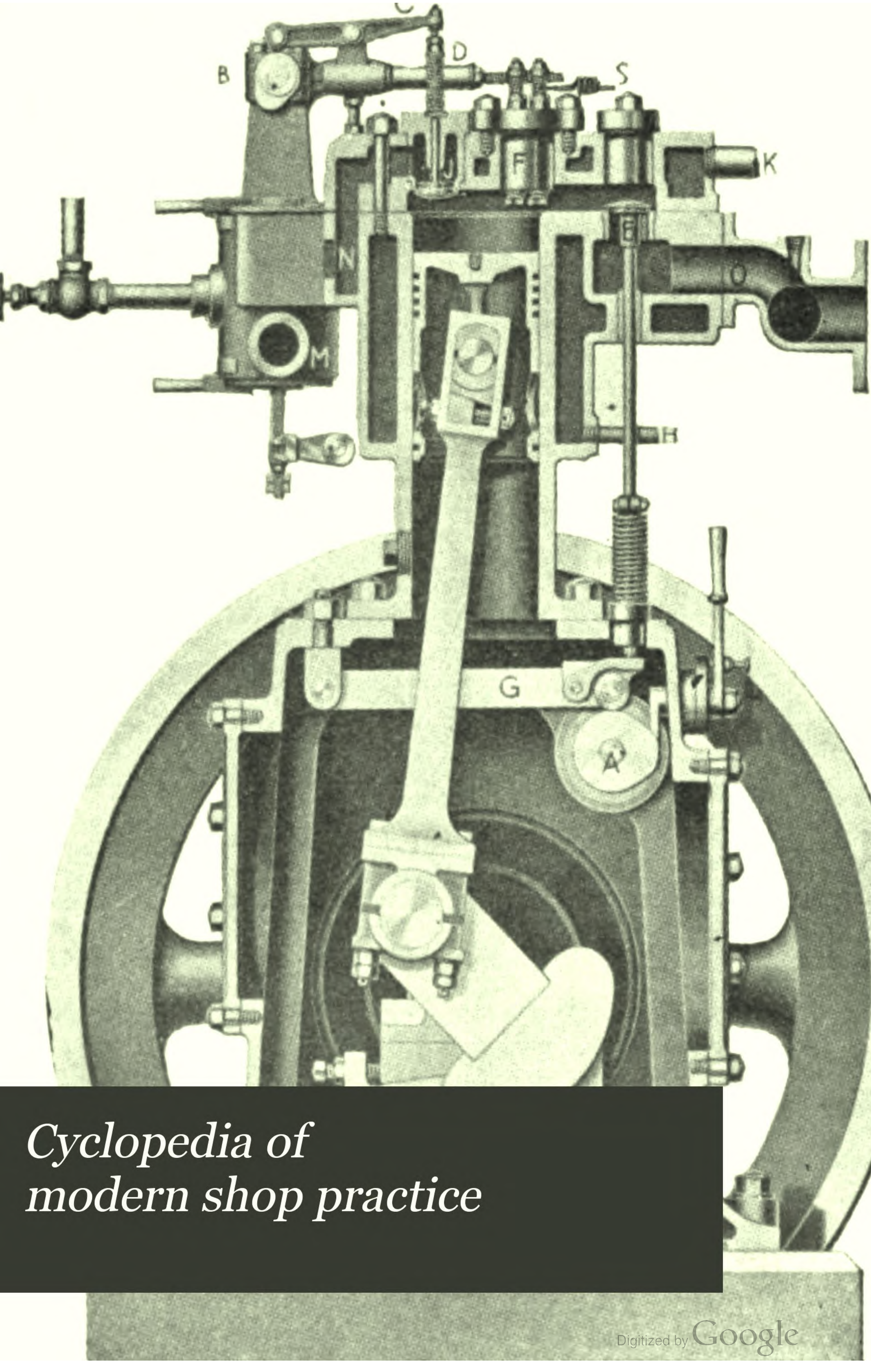
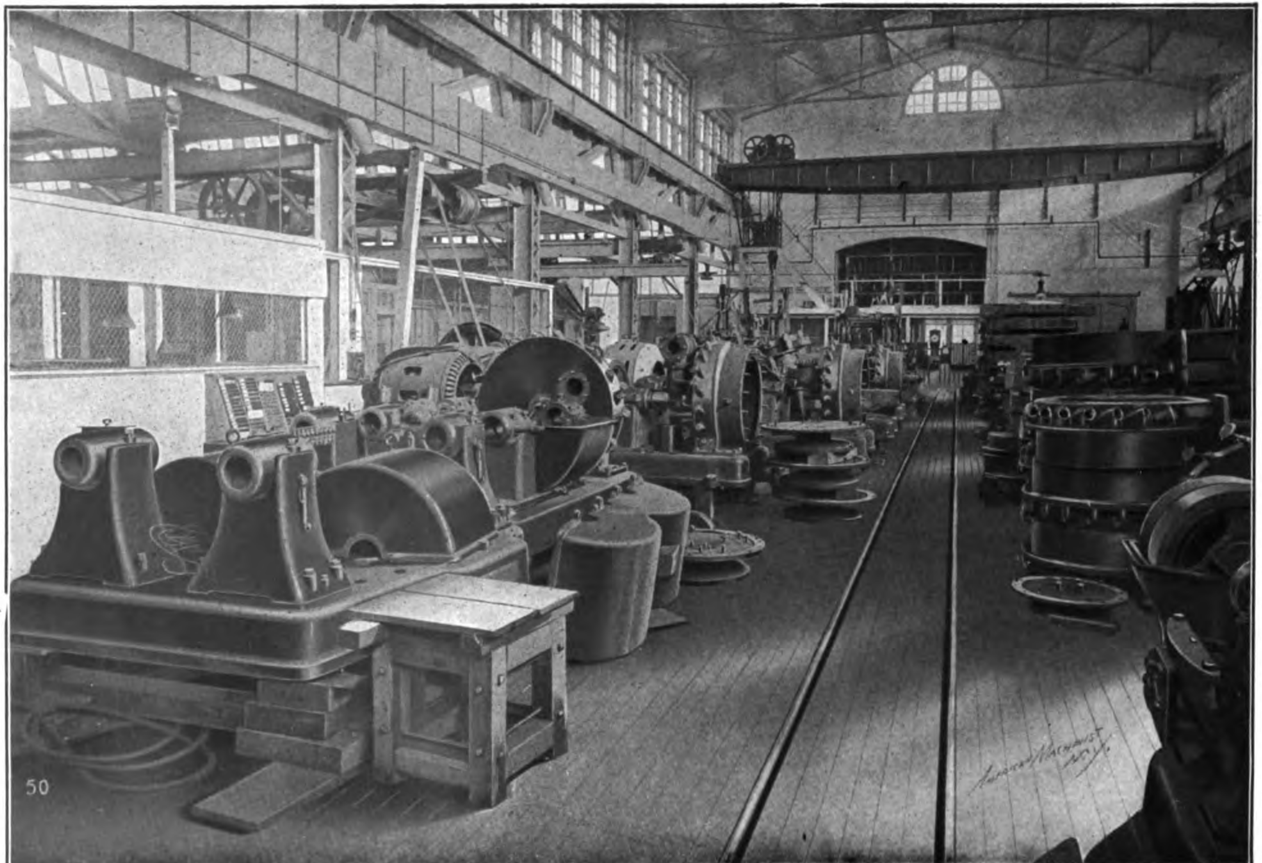
Cyclopedia of modern shop practice



3-VFG

Cyclopedia



ERECTING SHOP FOR LARGE STEAM TURBINES.
De Laval Steam Turbine Co.

CYCLOPEDIA

OF

Modern Shop Practice

v. 3

A Manual of

SHOP PRACTICE, PATTERN MAKING, MACHINE DESIGN, FOUNDRY AND MACHINE SHOP WORK, FORGING, TOOL MAKING, SHEET METAL WORK, STEAM, GAS AND OIL ENGINES, AUTOMOBILES, ELEVATORS, ELECTRICITY, ETC.

Editor-in-Chief

HOWARD MONROE RAYMOND, B. S.
DEAN, ARMOUR INSTITUTE OF TECHNOLOGY

Assisted by a Corps of

SHOP EXPERTS, DESIGNERS AND ENGINEERS

Illustrated with over Two Thousand Engravings

FOUR VOLUMES

CHICAGO
AMERICAN TECHNICAL SOCIETY
1906

Associate Editors—Continued

FREDERICK W. TURNER
Instructor in Machine Shop Work, Mechanic Arts High School, Boston.

JAMES RITCHEY
Instructor in Pattern Making, Armour Institute of Technology.

JAMES R. CRAVATH
Western Editor, "Street Railway Journal," Chicago.

RALPH H. SWEETSER, S. B.
Superintendent Algoma Steel Co., Ltd.
Formerly Instructor, Massachusetts Institute of Technology.
American Institute of Mining Engineers.

RAYMOND BURNHAM, M. E.
Associate Professor of Experimental Engineering, Armour Institute of Technology.

LEON H. RITTENHOUSE, M. E.
Head of Dept. of Engineering, Haverford College.
Formerly Instructor in Mechanical Engineering, American School of Correspondence.

MAURICE LeBOSQUET, S. B.
British Society of Chemical Industry.
American Chemical Society.

ERVIN KENISON, S. B.
Instructor in Mechanical Drawing, Massachusetts Institute of Technology.

WALTER H. JAMES, S. B.
Instructor in Mechanical Engineering, Massachusetts Institute of Technology.

EDWARD D. AGLE
Superintendent of Shops and Instructor in Machine Tool Work, Armour Institute of Technology.

LAWRENCE S. SMITH, S. B.
Instructor in Mechanical Engineering, Massachusetts Institute of Technology.

Associate Editors—Continued

ALFRED E. ZAPF, S. B.
Secretary, American School of Correspondence.

HARRY C. COFFEEN, M. S.
Assistant Professor of Machine Design, Armour Institute of Technology.

HELON BROOKS MACFARLAND, B. S., M. M. E.
Associate Professor of Mechanics, Armour Institute of Technology.

GEORGE L. FOWLER, A. B., M. E.
Consulting Engineer.
American Society of Mechanical Engineers.
American Railway Master Mechanics Association.

LAWRENCE K. SAGER, S. B., M. P. L.
Patent Attorney and Electrical Expert.
Formerly Assistant Examiner U. S. Patent Office.

L. ALLEN SOMMER
Instructor in Machine Tool Work, Armour Institute of Technology.

WILLIAM NEUBECKER
Instructor, Sheet Metal Department of N. Y. Trade School, formerly Superintendent Foerster Co.

JOHN LORD BACON
Instructor in Forge Work, Lewis Institute.
American Society of Mechanical Engineers.
Author of "Forge Practice."

EDGAR R. CREAMER
Instructor in Forging, Armour Institute of Technology.

WM. C. STIMPSON
Head Instructor in Foundry Work and Forging, Department of Science and Technology, Pratt Institute.

Associate Editors—Continued

Authorities Consulted

THE editors have freely consulted the standard technical literature of Europe and America in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well known treatises should be in the library of every engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines and machine tools; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

FRANCIS BACON CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University; Past President American Institute of Electrical Engineers.
Author of "Electric Lighting," "Practical Management of Dynamos and Motors."

SCHUYLER S. WHEELER, D. Sc.

Electrical Expert of the Board of Electrical Control, New York City; Member American Societies of Civil and Mechanical Engineers.
Author of "Practical Management of Dynamos and Motors."

WILLIAM M. BARR.

Member American Society of Mechanical Engineers.
Author of "Boilers and Furnaces," "Pumping Machinery," "Chimneys of Brick and Metal," etc.

SIMPSON BOLLAND.

Author of "The Iron Founder," "The Iron Founder's Supplement."

HORATIO A. FOSTER.

Member American Institute of Electrical Engineers; American Society of Mechanical Engineers; Consulting Engineer.
Author of "Electrical Engineer's Pocketbook."

J. FISHER-HINNEN.

Late Chief of the Drawing Department at the Oerlikon Works.
Author of "Continuous Current Dynamos."

WILLIAM F. DURAND, Ph. D.

Professor of Marine Engineering, Cornell University.
Author of "Resistance and Propulsion of Ships," "Practical Marine Engineering."

W. H. FORD, M. E.

Author of "Boiler Making for Boiler Makers."

Authorities Consulted—Continued

ROBEBT GRIMSHAW, M. E.

Author of "Steam Engine Catechism," "Boiler Catechism," "Locomotive Catechism," "Engine Runner's Catechism," "Shop Kinks," etc.

GARDNER D. HISCOX, M. E.

Author of "Gas, Gasoline and Oil Engines," "Horseless Vehicles, Automobiles and Motor Cycles," etc.

GEORGE C. V. HOLMES.

Whitworth Scholar; Secretary of the Institute of Naval Architects, etc.
Author of the "Steam Engine."

WILLIAM HOUGHTALING.

Author of the "Steam Engine and Its Appliance."

WILLIAM KENT, M. E.

Consulting Engineer; Member of American Society of Mechanical Engineers, etc.
Author of "Strength of Materials," "Mechanical Engineer's Pocketbook," "Steam Boiler Economy," etc.

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, University of Wisconsin; Member of American Society of Mechanical Engineers; American Institute of Electrical Engineers.
Author of "A Textbook on Electro-Magnetism and the Construction of Dynamos," "Alternating Currents and Alternating Current Machinery."

JOHN PRICE JACKSON.

Professor of Electrical Engineering, Pennsylvania State College; Member of American Institute of Electrical Engineers.
Author of "Alternating Currents and Alternating Current Machinery."

GAETANO LANZA, S. B., C. E., M. E.

Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology; Member of American Society of Mechanical Engineers, etc.
Author of "Applied Mechanics."

C. W. MacCORD, A. M.

Professor of Mechanical Drawing, Stephens Institute of Technology.
Author of "Movement of Slide Valves by Eccentrics."

MANSFIELD MERRIMAN, Ph. D.

Professor of Civil Engineering, Lehigh University; Member of American Society of Civil Engineers, etc.
Author of "Mechanics of Materials," "Treatise on Hydraulics," "Elements of Sanitary Engineering," etc.

CECIL H. PEABODY, S. B.

Professor of Marine Engineering and Naval Architecture, Massachusetts Institute of Technology.
Author of "Thermodynamics of the Steam Engine," "Tables of the Properties of Saturated Steam," "Valve Gears to Steam Engines," "Manual of Steam Engine Indicators," "Steam Boilers."

Authorities Consulted -Continued

EDWARD F. MILLER.

Professor of Steam Engineering, Massachusetts Institute of Technology.
Author of "Steam Boilers."

WILLIAM JOHN MACQUORN RANKINE, LL. D., F. R. S. S.

Civil Engineer; Late Regius Professor of Civil Engineering and Mechanics in University of Glasgow, etc.
Author of "Applied Mechanics," "The Steam Engine," "Civil Engineering," "Useful Rules and Tables," "Machinery and Mill Work," "A Mechanical Textbook."

KEMPSTER B. MILLER, M. E.

Consulting Engineer, and Telephone Expert.
Author of "American Telephone Practice."

MAURICE A. OUDIN, M. S.

Member of American Institute of Electrical Engineers.
Author of "Standard Polyphase Apparatus and Systems."

JOHN LORD BACON.

Instructor in Forge Work, Lewis Institute, Chicago; Junior member, American Society of Mechanical Engineers.
Author of "Forge Practice."

WILLIAM RIPPER.

Professor of Mechanical Engineering in the Sheffield Technical School; Member of the Institute of Mechanical Engineers.
Author of "Machine Drawing and Design," "Practical Chemistry," "Steam," etc.

JOSHUA ROSE, M. E.

Author of "Mechanical Drawing Self Taught," "Modern Steam Engineering," "Steam Boilers," "The Slide Valve," "Pattern Makers Assistant," "Complete Machinist," etc.

LAMAR LYNDON, B. E., M. E.

Consulting Electrical Engineer; Associate Member of American Institute of Electrical Engineers; Member of American Electro-Chemical Society.
Author of "Storage Battery Engineering."

ROBERT H. THURSTON, C. E., Ph. B., A. M., LL. D.

Director of Sibley College, Cornell University.
Author of "Manual of the Steam Engine," "Manual of Steam Boilers," "History of the Steam Engine," etc.

SYLVANUS P. THOMPSON, D. Sc., B. A., F. R. S., F. R. A. S.

Principal and Professor of Physics in the City and Guilds of London Technical College.
Author of "Electricity and Magnetism," "Dynamo-Electric Machinery," "Polyphase Electric Currents," "Electromagnet," etc.

W. S. FRANKLIN and R. G. WILLIAMSON.

Joint Authors of "The Elements of Alternating Current."

Authorities Consulted—Continued

EDWARD R. MARKHAM.

Consulting Mechanical Engineer.
Instructor in Machine Shop Work, Harvard University and Rindge Manual Training School; formerly Superintendent Waltham Watch Tool Co.
Author of "The American Steel Worker."

SAMUEL EDWARD WARREN.

Late Professor of Descriptive Geometry and Drawing, Massachusetts Institute of Technology.
Author of "General Problems in Shades and Shadows," "Shadows and Perspective," "Higher General Problems with Linear Perspective of Form," "Shadow and Reflection," etc.

THOMAS D. WEST.

Practical Moulder and Foundry Manager; Member American Society of Mechanical Engineers.
Author of "American Foundry Practice."

ROBERT WILSON.

Author of "Treatise on Steam Boilers," "Boiler and Factory Chimneys," etc.

WILLIAM C. UNWIN, F. R. S., M. Inst. C. E.

Professor of Civil and Mechanical Engineering, Central Technical College, City and Guilds of London Institute, etc.
Author of "Machine Design," "The Development and Transmission of Power from Central Stations," etc.

WILLIAM H. VAN DERVOORT, M. E.

Author of "Modern Machine Shop Tools."

J. A. EWING, M. A., B. Sc., F. R. S., M. Inst. C. E.

Professor of Mechanism and Applied Mechanics in the University of Cambridge.
Author of "The Steam Engine and Other Heat Engines."

ROLLA C. CARPENTER, M. S., C. E., M. M. E.

Professor of Experimental Engineering, Cornell University; Member of American Society Heating and Ventilating Engineers; Member American Society of Mechanical Engineers.
Author of "Heating and Ventilating Buildings."

JAMES E. HOMANS, A. M.

Author of "Self-Propelled Vehicles."

A. E. SEATON.

Author of "A Manual of Marine Engineering."

JAMES J. LAWLER.

Author of "Modern Plumbing, Steam and Hot Water Heating."

Introductory Note

THE successful education of the man in the shop is a question of vital importance. The difficulties under which he toils in his struggle for advancement, and his daily labor, render impossible the usual means of education, and prevent the attending of a resident technical school. Probably the most successful substitute for such a school is the correspondence method of instruction.

¶ Thousands of mechanics are improving their condition by devoting a half hour each day to systematic study under the direction of men who have had long experience in teaching, and in practical shop work. There are, however, many who cannot afford the time and expense necessary for a correspondence school course. For such the Cyclopedia of Modern Shop Practice is prepared.

¶ The instruction papers forming the Cyclopedia have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, many are in use as text books by Harvard University, Columbia University, Lehigh University, Iowa State College, the University of Maine, the U. S. Government in its School of Submarine Defense, the Westinghouse Companies in their Shop School, and for reference in the leading colleges, shops and public libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested, by actual use, for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

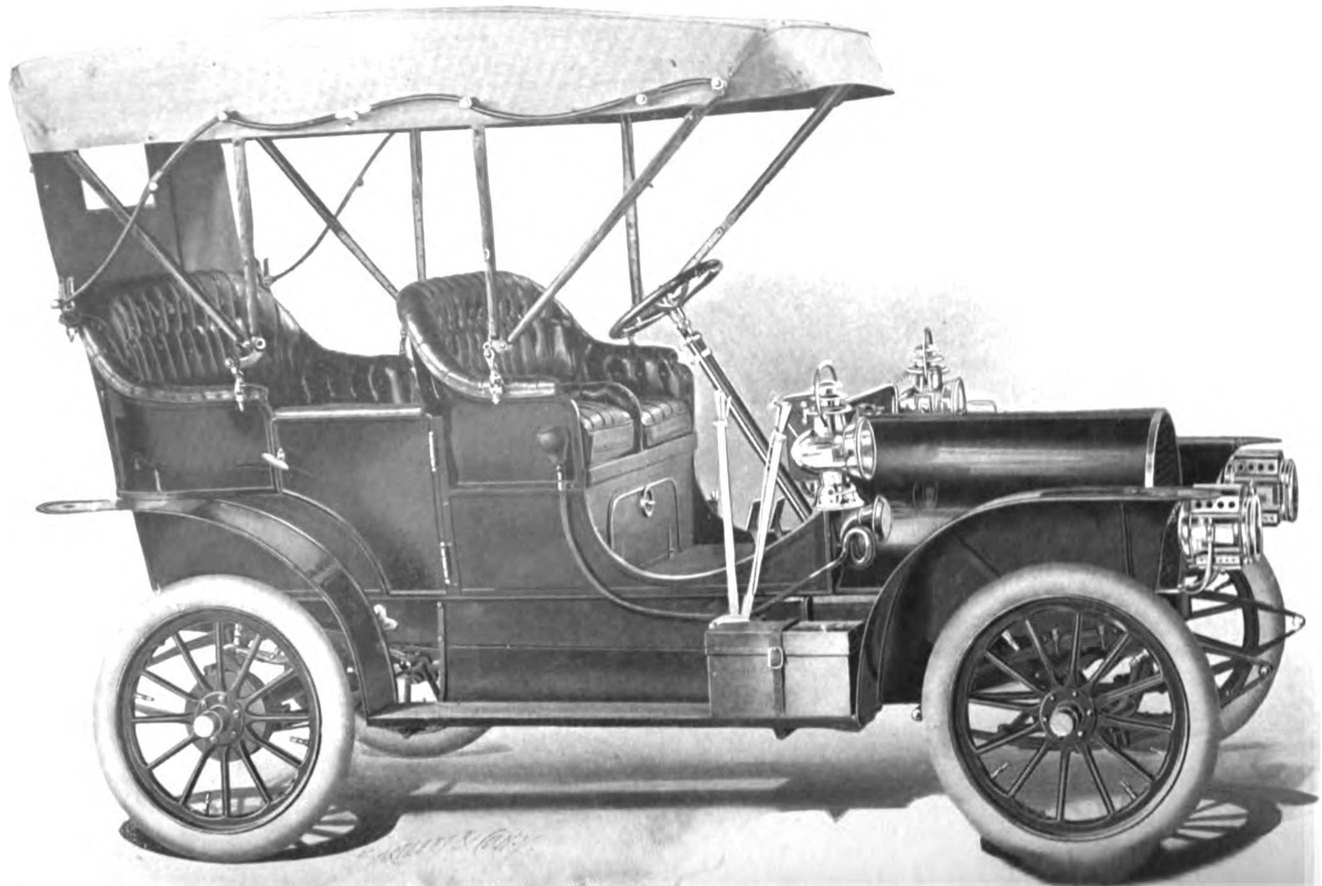
¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text book with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability — has alone made these volumes possible.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

Contents

PART III.



FRANKLIN FOUR-CYLINDER TOURING CAR

GAS AND OIL ENGINES.

The heat engine is at present the most important of all the available generators of power. Its purpose is to convert the heat of combustion of some fuel into work. Existing heat engines may be divided into two classes, according to where the combustion of the fuel takes place. In one class the combustion takes place entirely outside the working cylinder, and the heat of combustion is transmitted by conduction through the walls of a containing vessel to the substance which does the work. Such engines may be called *external combustion motors*. The most common example of this class is the steam engine; another example, which is but little used, is the hot-air engine. If the combustion takes place inside the engine itself, or in a communicating vessel, so that the products of combustion act directly on the engine, we have an engine of the second class—the so-called *internal combustion motors*. Gas and oil engines are the common examples of this type of motor.

THE EXTERNAL COMBUSTION MOTOR.

Engines of the second class have certain inherent advantages over external combustion motors. In the steam engine, practically the most perfect of the external combustion motors, the heat of combustion which is generated in the furnace passes through the plates of the boiler to the water on the other side. During this process about twenty-five per cent of the heat is wasted by radiation and by loss up the chimney in good modern plants. The water in the boiler is heated to a temperature which does not exceed 400° F. because at that temperature it has a pressure of nearly 250 lb. per square inch. If the water were heated to a much higher temperature, the pressure would be too great (for example, at 500° F. the pressure would be 700 lb.), requiring boilers and engines stronger than are at present practicable. The products of combustion in the furnace have a temperature which

is seldom less than 2,000° F. There is consequently a very large necessary drop of temperature as the heat passes through the boiler plates. The proportion of the total heat going to an engine that can be converted by the engine into work depends chiefly upon the temperature range of the working substance, and in the steam engine this range is made comparatively small—not exceeding 300° F.—because of the corresponding pressure limits. Consequently a steam plant not only loses much of its heat up the chimney, but also is able to convert but a small part of the heat that goes to the engine into work. In the best modern steam engines about twenty per cent. of the heat going to the engine is converted into work, and about sixteen per cent. of the heat of combustion of the fuel is converted into work in the best modern steam plants. The ordinary steam engine does not convert into work more than from six to ten per cent. of the heat of combustion of the fuel. An economical steam plant consists not cnly of boilers and engines, but also has a large number of auxiliaries, such as feed pumps, air pumps, condensers, feed water heaters, economizer, coal conveyers and steam traps. It requires considerable time and fuel to raise steam in the boilers before the plant can be put in operation after shutting down; or, if the fires are kept banked, so as to keep up steam pressure while the engines are not running, a not inconsiderable amount of fuel will be used for this purpose, without any corresponding work being done.

THE INTERNAL COMBUSTION MOTOR.

In the internal combustion motor where the fuel is a gas or volatile oil, there is no apparatus corresponding to a boiler and no losses corresponding to the boiler losses. If the fuel is coal, it has to be converted into gas before it can be used in an internal combustion motor, and thus necessitates the use of a gas producer in which some heat will be lost, though not so much as is usual in a boiler. The fuel being burned in the engine gives there a temperature of from 2,000° F. to 3,000° F., so that the temperature range in the engine is very large, and consequently the engine can be more efficient—that is, can convert a larger proportion of the heat of combustion into work than in a steam plant. The high temperatures are not necessarily accompanied by high pressures

because it is air and not water which is heated to that temperature. In practice the best internal combustion motors have converted thirty-five per cent. of the heat of combustion into work, or twice as much as the best steam engines, and the ordinary small gas engine will convert from fifteen to twenty per cent. of the heat of combustion into work. The internal combustion plant is also much simpler, having but few auxiliaries. The number of men necessary to run a large gas engine plant is small, the plant is ready to start up at a minute's notice, and the standing losses are very small or nothing. When a liquid fuel is used, the absence of boiler or other auxiliaries makes the internal combustion motor lighter, more compact, and more easily portable than any other motor. The absence of a boiler also does away with the risk of a disastrous explosion, and consequently there is no inspection required by law, no license for running the plant, and lower rates for insurance. The internal combustion motor is comparatively recent in its practical use. The last five years have brought about great improvements in its operation, a big increase in its use and large extension in its application. The internal combustion motor is less uniform in its speed of rotation, and is more liable to derangements than the steam engine, but these difficulties are rapidly being overcome, so that modern gas engines are used for electric lighting and have a reliability but little short of that of the steam engine.

The fuels that are used in external combustion motors may be solid, liquid or gaseous. In internal combustion motors, though, theoretically, the fuel may be in any of these three forms, the solid fuels are not practicable because the incombustible matter or ash present in them would rapidly destroy the rubbing surfaces in the cylinders. The actual fuels used are either gaseous or liquid, and the latter may be sent into the cylinder either as a vapor or as a liquid. There is no essential difference between engines using gas and those using oil; the cycle of operations occurring in the cylinder is the same with both kinds of fuel; the only differences are slight structural differences, with the addition of special apparatus for vaporizing the oil. The same engine can be, and often is, converted from a gas to an oil engine by merely changing valves.

In this paper whatever there is of thermodynamic theory applies to both gas and oil engines. The special features of oil engines are treated after the discussion of the gas engine.

HISTORY OF THE INTERNAL COMBUSTION MOTOR.

The history of the internal combustion motor begins with the invention of cannon. A gun is a motor in which the working substance is the gas resulting from the combustion of the powder and in which work is done on the projectile, giving it kinetic energy. Such a motor is not continuous in its action, but it offers possibilities of a practicable engine if the powder charge is small and the projectile or piston on which the gases act is restricted in its movement. The earliest internal combustion motors devised for doing useful work were intended to use gunpowder. The first of these was suggested by Abbé Hautefeuille in 1678, and was followed shortly by others, none of which were practically realizable in the then state of the mechanic arts.

It was not till the discovery by Murdock, near the end of the eighteenth century, that a combustible gas could be obtained from coal by a process of distillation, that a practical internal combustion motor was possible. As soon as the properties and method of manufacture of coal gas became known, numerous attempts were made to use it in engines. Until the year 1860 many engines were devised, patented, and in several cases constructed, operated and sold. None of these engines can be said to have been satisfactory. They were irregular in action, noisy, wasteful of fuel, and generally had practical defects.

The Lenoir Engine, which appeared in 1860, was the first really practical gas engine. Hundreds of these engines were made and sold, and the greatest interest in this type was aroused in France, where it was built, and in England, where it was largely used.

In general appearance the engine resembles a double-acting horizontal steam engine. The cylinder, shown in horizontal section in Fig. 1, has a separate admission port *a* and exhaust port *b* at each end. The valves are simple slide valves driven by eccentrics, and so designed that the inside edges alone uncover the ports. The valve G is used for the admission of the explosive mixture, which consists of air entering the valve cavity from *d* and gas coming through one of the branches *r* of the gas pipe and passing through the hole *i* in the valve. The air and gas enter the port *a* through a number of small holes in which they are

thoroughly mixed, and the mixture is exploded in the cylinder, when desired, by an electric igniter *n*. The exhaust is through the port *b* and the cavity in the exhaust valve H to the atmosphere. As the cylinder rapidly becomes very hot, it is provided with a water jacket.

The series or cycle of operations which takes place in this engine is as follows: During the first part of the stroke the admission valve G uncovers the port *a* so that a mixture of air and gas enters the cylinder, filling the space behind the piston. At

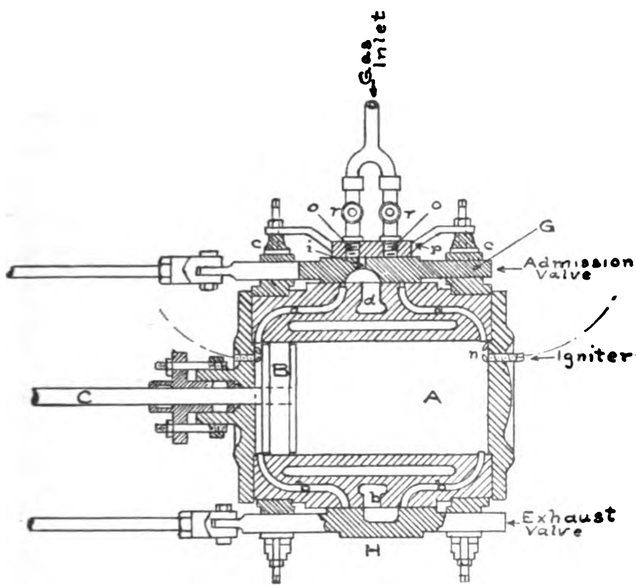


Fig. 1. Longitudinal Section of Cylinder of Lenoir Engine.

half stroke the valve closes the port and a spark from an induction coil passes between the terminals *n* of the electric igniter, exploding the mixture and raising its pressure to 60 or 70 lb. per square inch. The piston is then forced to the end of its stroke, the products of combustion expanding behind it. At the end of the stroke the valve H uncovers the exhaust port and keeps it open throughout the whole of the return stroke so that all the products of combustion are expelled to the atmosphere. A similar cycle of operations occurs on the other side of the piston. In Fig. 1 the valve G is just opening the port at the left so that admission may

take place there, and the valve H is just opening the port at the right so that exhaust may occur from the other end of the cylinder. A reproduction of an indicator card from this engine is shown in Fig. 2.

This engine gave considerable trouble in many cases, but the principal reason for the falling off in its use was the large amount of gas it required. It used from 60 to 70 cubic feet of coal-gas per I. H. P. per hour, or from three to four times as much as a modern gas engine, so that it did not compare very favorably with the steam engine in its running costs.

The Otto Cycle. In the year 1862 it was pointed out by a French engineer, Beau de Rochas, that in order to get high economy in a gas engine certain conditions of operation were necessary. The most important of these conditions is that the explosive mixture should be compressed to a high pressure before ignition. In order to accomplish this he proposed that the cycle of operations should occupy four strokes or two complete revolutions of the engine, and that the operations should be as follows:

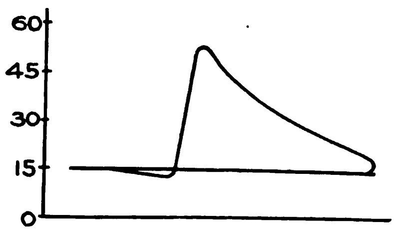


Fig. 2. Indicator Card of Lenoir Engine.

1. *Suction* or *admission* of the charge of gas and air throughout the complete forward stroke.

2. *Compression* of the explosive mixture during the whole of the return stroke so that it finally occupies only the clearance space.

3. *Ignition* of the charge at the end of the second stroke and *expansion* of the exploded mixture throughout the whole of the next forward stroke.

4. *Exhaust* beginning at the end of the forward stroke and continuing throughout the whole of the last return stroke.

This cycle was not actually used till 1876, when Dr. Otto adopted it in his engine and thereby produced the modern gas engine. The four-stroke cycle of Beau de Rochas is now universally known as the *Otto cycle.* In the past twenty years several other cycles, some of great merit, have been devised and used, but at

the present day an overwhelming majority of the existing internal combustion motors use the Otto cycle. The engines using this cycle are accordingly treated of first and at greatest length.

THE MODERN GAS ENGINE.

The construction of a modern gas engine using the Otto cycle is illustrated in the sectional elevation, Fig. 3, of a vertical engine. As in practically all Otto cycle engines, the engine is single-acting and has a long trunk piston which acts as a crosshead and also permits the use of several piston rings by which leakage past the piston is prevented even with the high pressure obtained by the explosion. The engine is made single-acting because the cylinder would get too hot for continuous running if it were double-acting; and moreover, a piston rod and stuffing box give great trouble if exposed to the high temperature of the burning gases. Since the cycle occupies two revolutions, the valves and igniter have to operate once in two revolutions, and therefore the cams which drive these parts are mounted on shafts running only half as fast as the main shaft.

Referring to Fig. 3, A is the shaft which carries the exhaust valve cam, and is driven by gears from the main shaft. The exhaust cam works against a roller carried on the free end of the guide lever G. The exhaust valve E has a long stem projecting downward and resting on a hardened steel plate on the upper side of the guide lever G. The spring surrounding the stem serves to bring the exhaust valve back to its seat and to keep the stem in contact with the guide lever. From the exhaust cam shaft A a horizontal shaft with bevel gears leads to the opposite side of the engine, engaging with a vertical shaft which in turn drives the upper cam shaft B. Incidentally, the vertical shaft carries the governor. The upper cam shaft carries two cams. One engages against a roller on the end of the horizontal lever C. As the throw side of this cam comes uppermost, the opposite end of the lever C depresses the stem of the inlet valve J, opening the latter for the admission of the mixture of gas and air. A spring on the stem of the inlet valve furnishes a means for closing it and keeping the cam and roller always in contact with each other. Immediately adjacent to the inlet valve cam is the igniter cam, which at the

proper instant operates a horizontal plunger working through the guide D to break the electric current through the wire S at the terminals of the igniter F.

The cylinder heads and the upper end of the cylinder are thoroughly water-jacketed, as, owing to the extreme heat to which

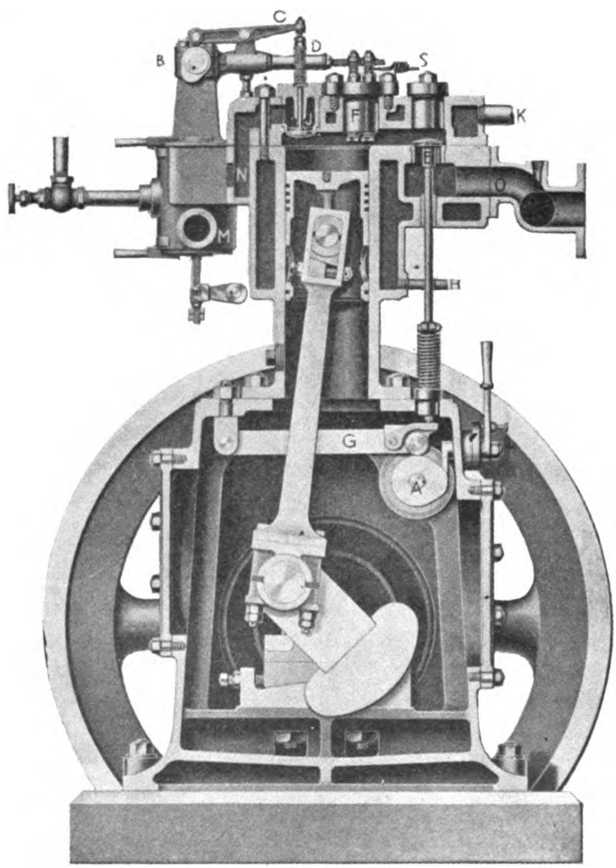


Fig. 3. Westinghouse Gas Engine.

these parts are subjected, they would soon become red-hot if no means were provided for keeping the temperature down. The cooling water enters at H and is discharged at K.

The gas and air enter the mixing chamber M by separate inlets, in proportionate amounts which can be regulated, and the mixture is conducted through a distributing chamber to the port

N leading to the cylinder head in which the inlet valve is located The exhaust gases escape through O.

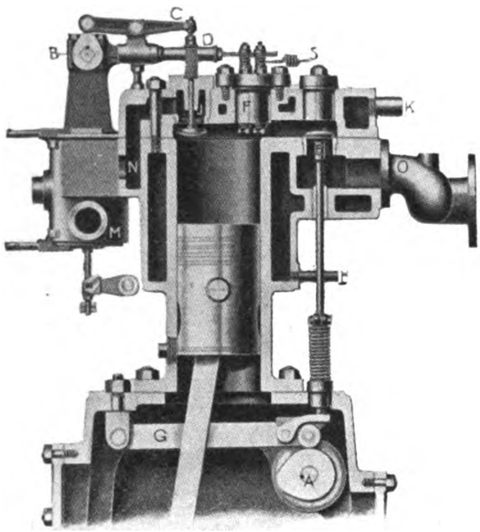


Fig. 4. Admission of the Charge.

The operation of this engine is illustrated in the accompanying illustrations. The admission of the charge of air and gas takes place during the first downward stroke of the engine (Fig. 4). The exhaust valve E is closed and the admission valve J is open, and closes only when the piston is at the end of the stroke and the cylinder is full of the explosive mixture. During the return stroke (Fig. 5) both valves are closed and the charge is compressed till at the end of the stroke it occupies only the clearance space. Shortly before the end of the stroke the igniter cam has brought the igniter terminals into contact, completing an electric circuit. When the crank is nearly on its dead center the igniter terminals are separated by the action of a coiled spring in the guide D, and as they fly apart the circuit is broken and a spark passes between the terminals (Fig. 6), igniting the charge. An immediate

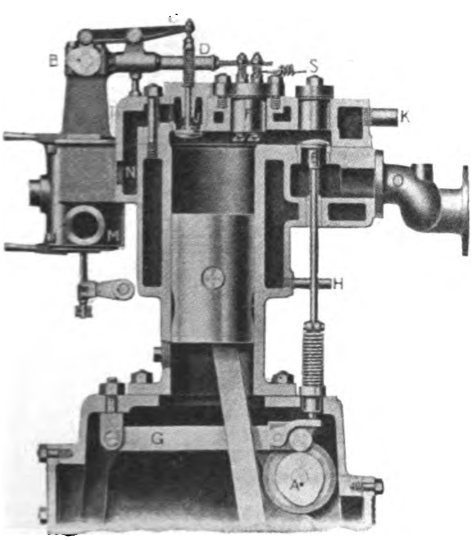


Fig. 5. Compression.

rise of pressure occurs and the piston is forced downward, both valves remaining closed until just before the end of the down stroke, when the exhaust valve E opens.

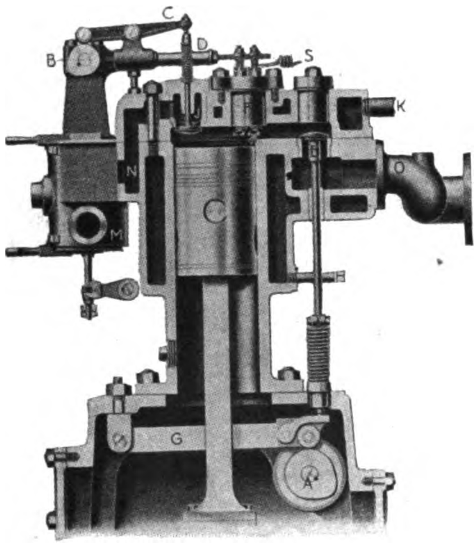


Fig. 6. Ignition.

During the whole of the last return stroke (Fig. 7) the exhaust valve E remains open and the products of combustion are forced through O to the atmosphere. The exhaust valve closes as the piston completes the stroke, and everything is in readiness to recommence the cycle.

Another form of vertical engine using the Otto cycle is shown in vertical section in Fig. 8. In this engine there are three valves—the inlet valve *b* for the gas, the inlet valve *a* for the explosive mixture, and the exhaust valve. All three valves are operated from the shaft *c* which is driven from the main shaft by spur gearing, reducing the speed to one-half that of the main shaft. A cam on the shaft *c* lifts the pivoted lever *d* at the end of which is the long spindle of the valve *a* through which the charge is admitted. The spindle carries an arm *e* which comes in contact with a short link on the

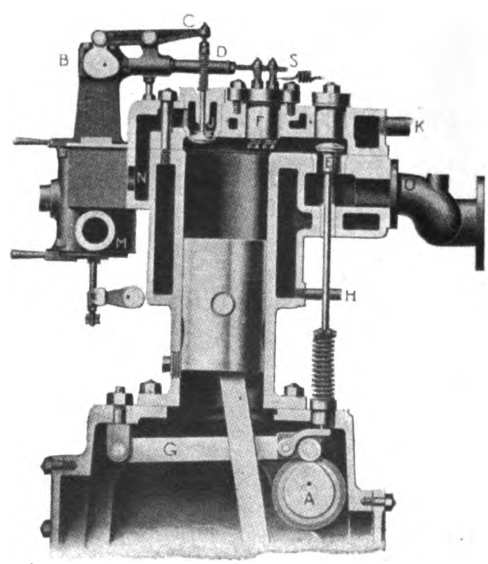


Fig. 7. Exhaust.

stem of the gas admission valve b whenever an explosive charge is required, so that both the valves a and b are open at the same time. The space g behind the valve a and around the valve b is in free communication with the atmosphere. With a open and the piston decending, air is drawn in and thoroughly mixed with the gas

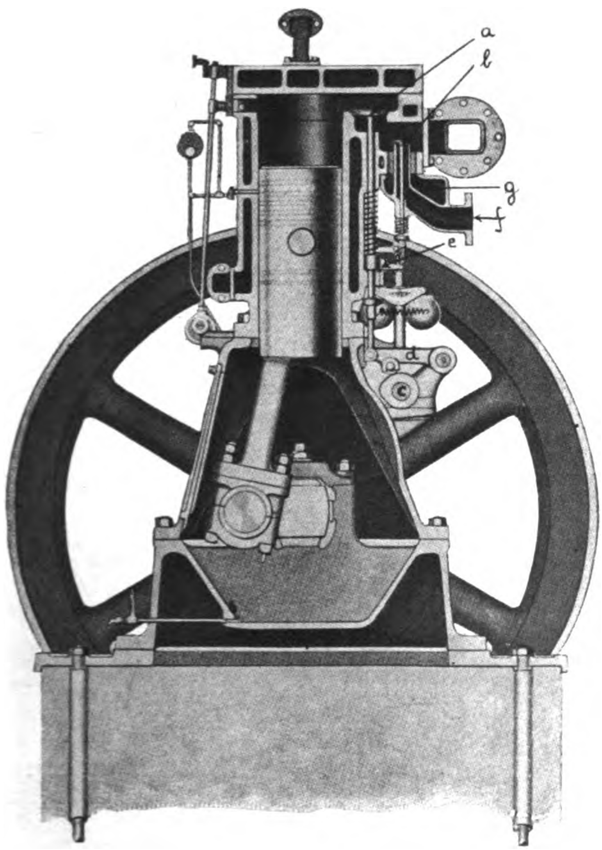


Fig. 8. Nash Gas Engine.

while passing through a. If the governor throws the short link to one side, the arm e does not come in contact with it, the gas valve does not open and air alone is taken into the cylinder during the admission stroke. The exhaust valve is behind the admission valve but is not shown in the diagram.

An example of the horizontal form of gas engine is given in Fig. 9, which is a vertical cross section through the cylinder and valves. The valve *a* for the admission of the explosive mixture acts automatically, opening when the pressure in the cylinder falls below the atmospheric pressure. The exhaust valve *b* is opened at the proper time by the action of the cam *c*, which, acting on a roller *d* at the extremity of one arm of the bell crank lever fulcrumed at *e*, pulls the rod *f* to the left and through the bell crank lever fulcrumed at *g* lifts the exhaust valve as shown. The cam *c* is mounted on a shaft which is driven through the spur wheel *k*

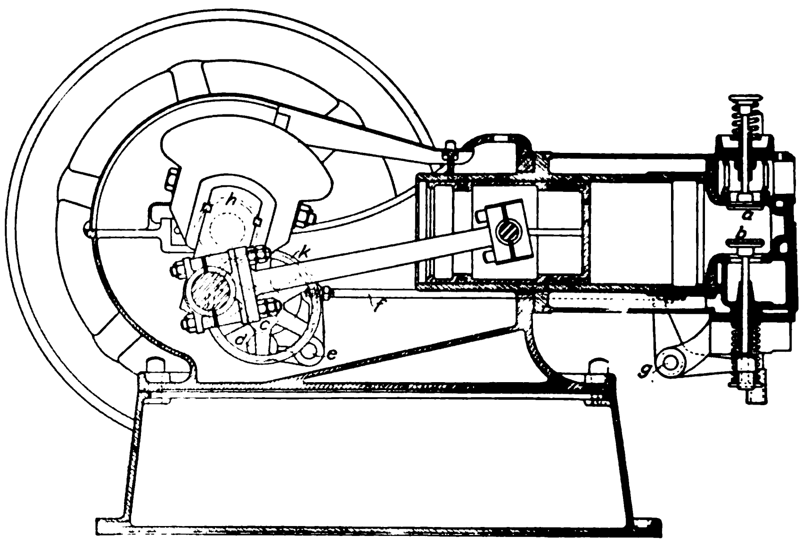


Fig. 9. Olds Engine.

by the spur wheel *h* (dotted) on the crank shaft. The wheel *k* has twice as many teeth as the wheel *h*, and consequently the cam shaft revolves only half as fast as the main shaft.

Another horizontal engine is illustrated in Figs. 10, 11 and 12. In this case the admission valve B and the exhaust valve D are both horizontal, a position which can be used satisfactorily only for engines of small size. The air goes to the admission valve through the pipe N, and is shown as taken from the base of the engine. The gas mixes with it at H (Fig. 10), entering through a nozzle. The amount of gas entering is controlled by the throttle

valve A (Fig. 11), and the time at which it enters is determined by the valve G, which is opened at the desired time through the action of the cam P (Fig. 11). The cam P coming in contact with the roller Q at the end of the lever fulcrumed at R, gives a movement to the rod S which is transmitted to the valve through the levers best seen in Fig. 12. The admission valve B is automatic in its action. The exhaust valve D is opened by the action of the cam T (Fig. 10) acting on the roller U at the end of the valve rod W. The valve rod is supported near its free end by the lever X. Both the cams P and T are on a shaft driven from the crank shaft by spur wheels. The governor (Fig. 12) is of the fly-wheel type

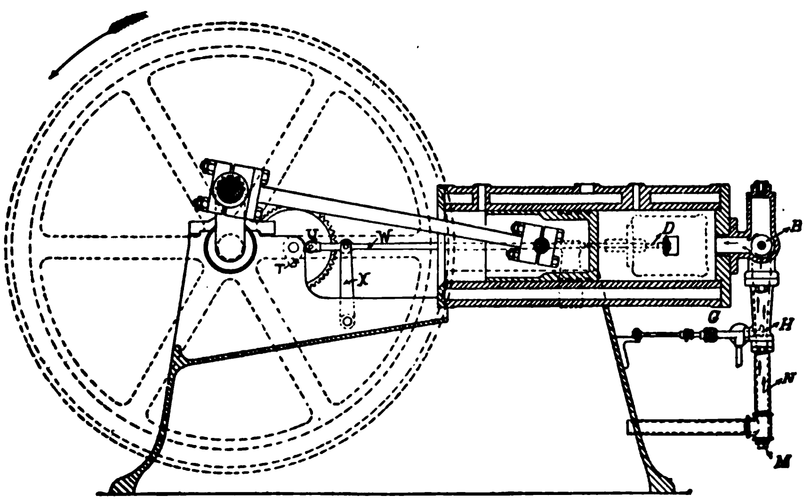


Fig. 10, Charter Engine. Sectional Elevation.

and consists of the balls which are held by spiral springs and which operate a sleeve on the main shaft. When the engine is above speed, the movement of the sleeve throws the roller Q out of line with the cam P, and consequently there is no admission of gas to the cylinder.

The inlet and exhaust valves in gas engines are nearly always *poppet* or *mushroom* valves similar to those shown in Figs. 4 to 11. The exhaust valves are nearly always mechanically operated; the main inlet valves are often automatic. The automatic valve is similar to a pump suction valve and is kept on its seat by a weak spring (*a*, Fig. 9) and only opens when the pressure

in the cylinder is sufficiently less than the atmospheric pressure to permit the latter to overcome the resistance of the spring. Consequently the suction or admission pressure in the gas engine is necessarily low when automatic inlet valves are used. The effect is to decrease the work done by the engine and also its efficiency; the only advantage is the greater simplicity. Most small gas engines have automatic inlet valves.

A positively actuated admission valve is shown in Fig. 13. The valve is lifted by a cam *a* on the side shaft *b* through the lever fulcrumed at *c*. The valve closes by its own weight, assisted by a spring, and is guided in its motion by a long sleeve. The valve chest is completely water-jacketed.

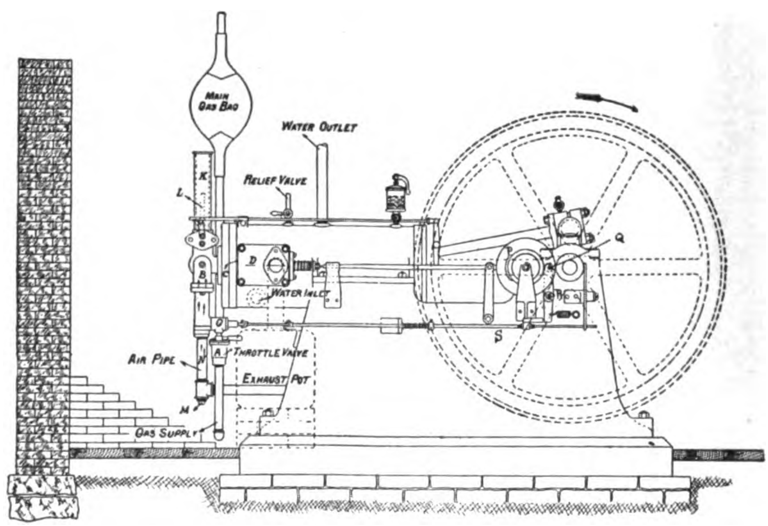


Fig. 11. Charter Engine. Side View.

The pressure in the cylinder when the exhaust valve opens is generally from 25 to 45 lb. above the atmospheric pressure, and the exhaust valve has to be lifted against this pressure. With a mushroom valve 4 in. in diameter, and with 40 lb. pressure per square inch at the end of expansion, there would be a total pressure of about 500 lb. on the valve at the time when it is to be lifted. It is desirable to reduce the strain on the valve and valve mechanism, and in large engines this is sometimes done by balancing the valve. A balanced exhaust valve *e* of the piston valve type is

shown in Fig. 14 in its valve chest or housing. The connection with the cylinder is at *d* and the valve seat is the conical seat *a*. A hole *f* through the valve ensures the existence of atmospheric pressure on top of the valve, and the exhaust gases escape through *g* to the atmosphere. To prevent excessive heating of this valve water is circulated through it, entering at *b* and leaving at *c*.

In smaller engines the pressure on the exhaust valve just prior to its opening is sometimes relieved by the escape of the gases through an auxiliary exhaust port (P, Fig. 15) in the cylin-

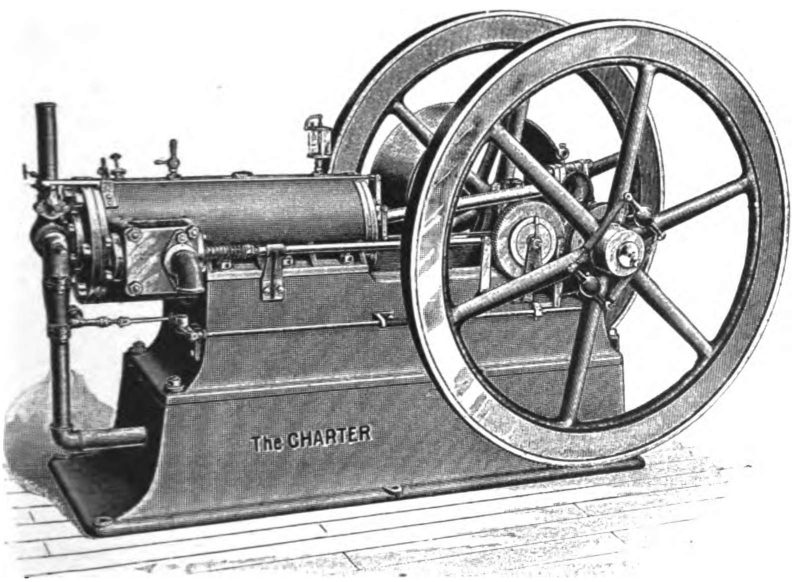


Fig. 12. Charter Engine.

der which is uncovered by the piston just before it reaches the end of its outstroke. Soon after it starts on the return stroke the piston covers the auxiliary port, and the exhaust for the remainder of the stroke is through the regular exhaust valve. As the regular valve (not shown in the figure) is not opened till after the uncovering of the auxiliary port, there is practically only atmospheric pressure on it when it lifts. An objection to this device is that the same auxiliary port is uncovered again near the end of the admission stroke, and as the pressure in the cylinder is then less than atmospheric pressure, some of the exhaust gases enter the

cylinder, mixing with the charge and diluting it. At the beginning of the return or compression stroke part of the contents of the cylinder is forced out to the exhaust until the piston has again covered the auxiliary port, and consequently some of the charge is lost.

Valve Gearing. The valves are most commonly operated by cams. Cams are preferable to eccentrics for this purpose, because they can be designed to give very prompt opening and closing. The cams are mounted upon a *lay shaft*, or *side shaft*, or *cam shaft*. The cam shaft is driven in different engines either by spur gears, bevel gears, or skew gears. The spur gear (see Fig. 12) can

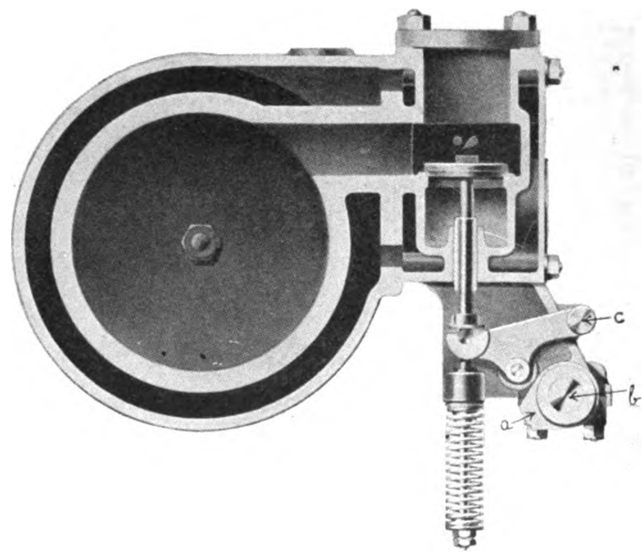
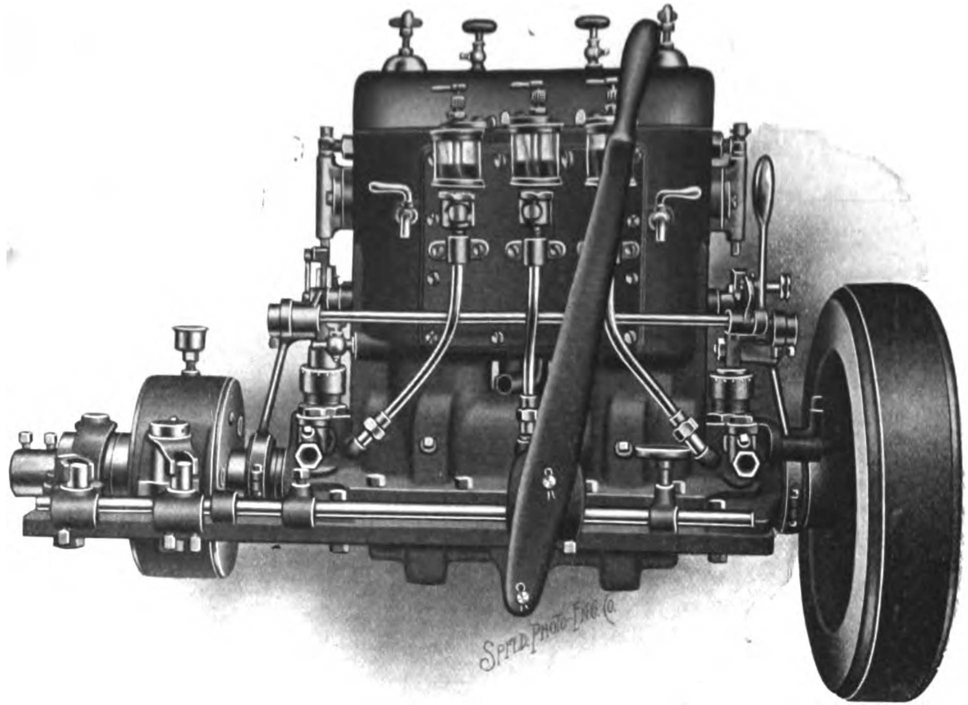


Fig. 13. Buffalo Engine. Cross-Section of Cylinder and Valve Chest.

be used only for parallel shafts, the bevel gear for shafts which are in the same plane but are inclined to one another, and the skew or spiral gear (Fig. 16) for shafts which are not parallel and do not lie in the same plane. To reduce the speed of the cam shaft the spur and bevel gears must have the gear on the cam shaft twice the size of that on the main shaft. With the skew gear there is no necessary relation between the diameter of the two gears, and generally the gear on the cam shaft is smaller than that on the main shaft. The skew gear has great advantage over the other two in its quietness of operation.



TOQUET MARINE MOTOR.
Starboard Side with Reverse Gear.

THERMODYNAMICS OF THE OTTO CYCLE.

In internal combustion motors the explosive mixture in the cylinder consists of air mixed with a comparatively small volume of the gaseous or liquid fuel. For instance, if the engine uses gas from the city mains, the mixture will average about eight or nine parts of air to one of gas and should never have less than about six parts of air to one of gas. This mixture can be regarded up till the time when explosion takes place as if it were pure air. Also, the products of combustion, after the explosion is completed, have physical properties but very slightly different from those of air, and consequently the working substance in the cylinder can be regarded without serious error as consisting entirely of air. In the following discussion of what occurs in the engine cylinder, it is assumed throughout that the substance in the cylinder is air.

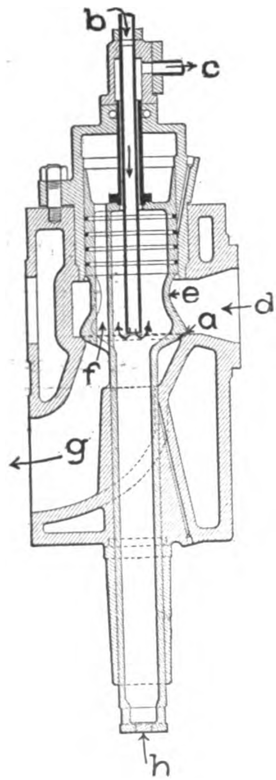


Fig. 14. Balanced Exhaust Valve.

The processes taking place in the engine cylinder are best represented on a pressure-volume diagram. At the beginning of the cycle of operations the piston is at the end of its path and is about to begin its out-stroke. The clearance space is full of products of combustion at atmospheric pressure because it has been in communication with the atmosphere through the exhaust valve which has just closed. The condition existing in the cylinder at this instant is represented in the diagram, Fig. 17, by the point 1, which is at a horizontal distance from the vertical axis representing the clearance volume, and at a vertical distance above the horizontal axis representing the atmospheric pressure of 14.7 lb. per square inch. As the piston makes its out-stroke the admission valve opens admitting the charge to the cylinder throughout the stroke, and as the cylinder is in com-

munication with the outside air through the air admission valve, the pressure in the cylinder remains atmospheric pressure throughout the stroke. On the diagram the admission is represented by the line 1 2, which is at the constant height representing the atmospheric pressure and whose length represents the volume of the charge taken in, which is the same as the volume through which the piston moves. The point 2 represents the condition at the end of the first stroke. The admission valve now closes and the piston makes its return stroke. Since all the valves are closed,

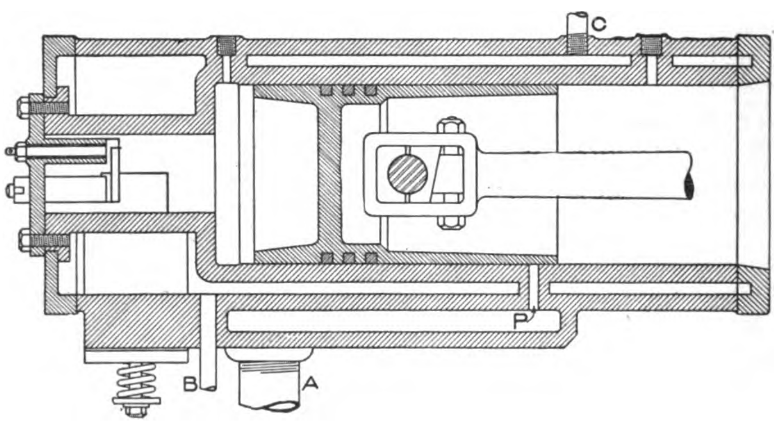


Fig. 15. Section Through Cylinder, Columbus Engine

the charge cannot escape and is crowded into a smaller volume while its pressure rises. The process continues till the piston reaches the end of its stroke, at which time the whole charge is compressed into the clearance space. This process is represented by the line 2 3, which shows the rise in pressure resulting from the compression. A compression of this kind, occurring without the addition or the abstraction of heat from the gas, is called an *adiabatic* compression. It causes not only an increase in the pressure but also in the temperature of the gas. It is the process that takes place in the working of an ordinary bicycle pump and which causes its rise in temperature. The relation between the pressure of air and its volume when subjected to adiabatic compression is

$$PV^{1.405} = \text{constant}$$

(Note carefully that in this equation P means the absolute pressure and not the pressure shown by a gauge). When the charge has reached the conditions represented by the point 3, it is ignited, and the heat generated by the explosion raises the temperature and consequently the pressure of the mixture. The combustion occurs so rapidly that the piston has not time to start on the out-stroke before the combustion is completed and the rise of pressure occurs, as is shown by the line 3 4, while the volume of the gas is constant. The hot products of combustion at the pressure P_4 now force the piston out and, expanding behind it, they fall in pressure. This expansion, occurring without communication of heat to or from the gas is *adiabatic expansion*, and is consequently accompanied by a fall in temperature of the gas. The expansion curve 4 5 is similar to the compression curve 2 3, and has the same equation.

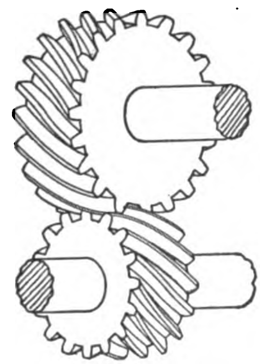


Fig. 16. Spiral Gear.

At the point 5 the piston is at the end of the stroke and no more expansion is possible. The exhaust valve opens and the pressure in the cylinder falls immediately to atmospheric pressure, as shown by the line 5 2 in the diagram. Throughout the last return stroke, 2 1, the exhaust valve remains open so that the pressure in the cylinder remains atmospheric pressure. The completed diagram, Fig. 17, shows the whole series of pressure and volume changes occurring in a gas engine, and is such a diagram as would be taken by an indicator from a perfect engine. The area 2 3 4 5 enclosed by the diagram represents the work done by the engine per cycle.

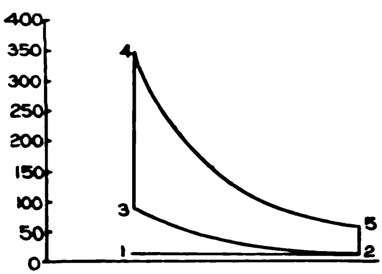


Fig. 17. Ideal Indicator Card of Otto Cycle.

The Pressures and Temperatures of the working substance and the amount of work done in an engine which exactly follows the Otto cycle can be readily calculated. Starting at the point

2 (Fig. 17), there is present in the cylinder a volume V_2 at atmospheric pressure P_2 and at the temperature t_2, which will be assumed to be the temperature of the air as it came into the cylinder. The working substance is compressed adiabatically till it fills only the clearance volume V_3. The consequent rise in pressure can be calculated from the formula already given, but it is more simply obtained from the curve, Fig. 18, which gives the relation between the changes of volume and of pressure in adiabatic expan-

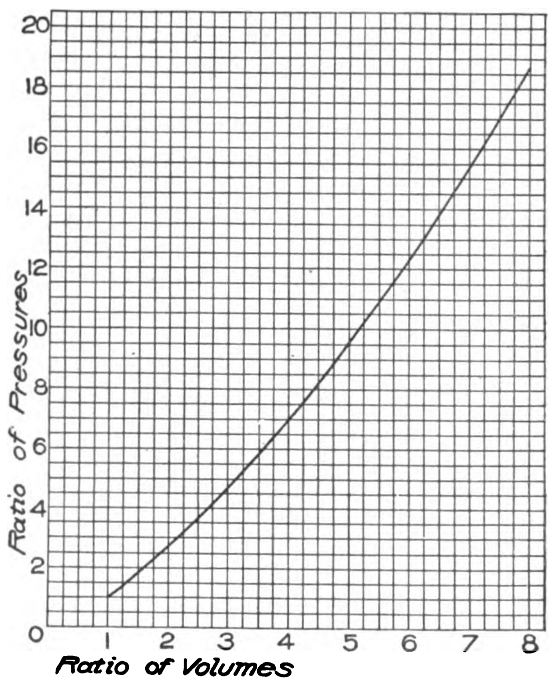


Fig. 18. Adiabatic Expansion.

sion or compression. The horizontal scale in this diagram is the ratio of expansion or compression, and the vertical scale shows the corresponding ratio of the pressures at the beginning and end of the expansion or compression. If, for example, the working substance expands adiabatically to five times its original volume, the pressure (which varies inversely as the volume) is shown by the curve to fall to $\frac{1}{9.67}$ of its original value. Conversely, if the

working substance is compressed to $\frac{1}{5}$ the original volume, the pressure rises to 9.67 times its original value. Consequently, the pressure at the point 3, Fig. 17, can be found by the use of this curve.

Example. A gas engine with $33\frac{1}{3}$ per cent clearance takes in its charge at 14.7 lb. per sq. in. pressure. What is the pressure at the end of the adiabatic compression?

Solution. The clearance volume V_3 is $33\frac{1}{3}$ per cent of the volume, $V_2 - V_3$, through which the piston moves, or

$$V_3 = \frac{33\frac{1}{3}}{100}(V_2 - V_3)$$

$$\therefore \quad 3V_3 = V_2 - V_3$$

$$\text{and} \quad \frac{V_2}{V_3} = 4$$

From the curve, Fig. 18, if the ratio of compression is 4, the corresponding ratio of pressures is 7.06, so that the pressure at the end of compression is 7.06 times the pressure at the beginning of compression. Therefore the pressure at end of compression, $P_3 = 7.06 \times 14.7 = 103.8$ lb. per sq. in. abs.

The temperature at the end of the adiabatic expansion can be found from the equation for a perfect gas. This may be stated in the form

$$PV = wRT$$

where w is the weight of the gas, R is a constant for any perfect gas and has the value 53.2 for air, P is the pressure in lb. per sq. ft. abs., and T is the absolute temperature of the gas. The weight of the gas is constant throughout the adiabatic compression, and can be found from the point 2 if P_2, V_2 and T_2 are known. The temperature at 3 can then be found from the equation

$$P_3V_3 = wRT_3$$

Example. Assuming the conditions of the previous problem and supposing the temperature of the air to be 60° F., what is the temperature of the charge at the end of the compression?

Solution.

$$P_2V_2 = wRT_2$$

$$\therefore \quad wR = \frac{P_2V_2}{T_2} = \frac{14.7 \times 144 \times V_2}{60 + 461}$$

Also

$$T_3 = \frac{P_3V_3}{wR}$$

$$= P_3 \frac{V_3}{V_2} \times \frac{60 + 461}{14.7 \times 144}$$

and

$$\frac{V_3}{V_2} = \frac{1}{4}$$

$$\therefore \quad T_3 = 103.8 \times 144 \times \frac{1}{4} \times \frac{521}{14.7 \times 144}$$

$$= 919.6^\circ \text{ abs.}$$

and

$$t_3 = 458.6^\circ \text{ F.}$$

The rise in temperature during explosion depends on how much heat is generated which in turn depends on the strength of the explosive mixture and the heat of combustion of a cubic foot of the fuel. Let H be the heat of combustion of a cubic foot of the fuel in B. T. U., and let the mixture consist of 1 part of gas to n parts of air. The total volume of the charge taken into the cylinder each admission is

$$V_2 - V_1 \text{ cu. ft.}$$

the volume of fuel in this charge

$$\frac{1}{n+1}(V_2 - V_1)$$

and the heat of combustion of this fuel is

$$Q = H\frac{V_2 - V_1}{n+1} \text{ B.T.U.}$$

This heat is utilized in raising the temperature of the gas from the known temperature T_3 to another temperature T_4. The rise in temperature can be found when the heat necessary to raise one pound of air one degree in temperature is known. This amount of heat is called the *specific heat.* It is represented by the symbol C_v (indicating that the volume is unchanged while the temperature rises), and is equal to .169 B.T.U. for air. With a weight of w

lb. the heat necessary to raise the gas one degree in temperature is

$$wC_v \text{ B.T.U.}$$

To raise the temperature $T_4 - T_3$ degrees the heat supply is

$$w\, C_v\, (T_4 - T_3) \text{ B.T.U.}$$

and the heat of combustion is used entirely in raising the gas from T_3 to T_4.

$$\therefore \quad H\frac{V_2 - V_1}{n+1} = w\, C_v\, (T_4 - T_3)$$

$$= \frac{P_2V_2}{RT_2} C_v\, (T_4 - T_3)$$

$$T_4 - T_3 = \frac{H}{n+1} \times \frac{RT_2}{P_2} \times \frac{1}{C_v} \times \frac{V_2 - V_1}{V_2}$$

Example. In the previous problem if the charge taken in consists of 1 part of gas to seven parts of air and the heat of combustion of the gas is 640 B.T.U., per cu. ft., find the temperature at the end of explosion.

Solution.

$$\frac{V_2 - V_1}{V_2} = \frac{V_2 - \frac{1}{4}V_2}{V_2} = \frac{3}{4}$$

$$T_4 - T_3 = \frac{640}{8} \times \frac{53.2 \times 521}{14.7 \times 144} \times \frac{1}{.169} \times \frac{3}{4}$$

$$\therefore \quad T_4 = 4649 + T_3$$

$$= 5568.6^\circ \text{ abs.}$$

$$\therefore \quad t_4 = 5107.6^\circ \text{ F.}$$

If a perfect gas is raised in temperature while its volume is unchanged, the absolute pressure will increase in exact proportion to the rise of absolute temperature,

or

$$P_4 : P_3 :: T_4 : T_3$$

$$\therefore \quad P_4 = \frac{T_4}{T_3} P_3$$

Example. What is the pressure at the end of explosion in the preceding problem ?

Solution.

$$P_4 = \frac{T_4}{T_3} P_3$$
$$= \frac{5568.6}{919.6} \times 103.8 \text{ lb. per sq. in. abs.}$$
$$= 628.6 \text{ lb. per sq. in. abs.}$$

The pressure and temperature at the end of the adiabatic expansion can be found most simply, after the other pressures and temperatures are known, by making use of a relation which exists between the pressures and temperatures at the points 2, 3 4. 5.* These relations are

$$\frac{P_2}{P_3} = \frac{P_5}{P_4}$$

and

$$\frac{T_2}{T_3} = \frac{T_5}{T_4}$$

Examples. What are (a) the pressures and (b) the temperatures at the end of the adiabatic expansion in the preceding problem?

(a) $P_5 = \frac{P_2}{P_3} \times P_4 = 89$ lb. per sq. in. abs.

(b) $T_5 = \frac{T_2}{T_3} \times T_4 = 3155°$ abs.

$= 2694°$ F.

The work done by any heat engine is equal to the difference between the heat that goes to the engine and that which is rejected by the engine, because whatever heat disappears cannot have been destroyed and must have been converted into work. In the Otto cycle the heat taken in has been seen to be

$$Q = wC_v (T_4 - T_3) \text{ B.T.U.}$$

Heat is rejected from the engine only during the process represented by the line 5 2, because when the charge gets back to the condition 2, it has returned to its original volume and pressure

* The ratio of the pressures $\frac{P_4}{P_5}$ can be obtained from the curve, Fig. 18, since the ratio of the volumes $\frac{V_5}{V_4}$ is known. But $V_5 = V_2$, therefore $\frac{V_5}{V_4} = \frac{V_2}{V_3}$ and $\frac{P_3}{P_2} = \frac{P_4}{P_5}$

and consequently to its original temperature. The heat rejected is then

$$Q_R = wC_v\,(T_5 - T_2)\ \text{B.T.U.}$$

And consequently the work done per cycle is

$$\begin{aligned} W &= Q - Q_R\ \text{B.T.U.} \\ &= 779\,(Q - Q_R)\ \text{ft. lb.} \end{aligned}$$

The efficiency of the cycle, that is, the fraction of the heat supplied that is converted into work is

$$\begin{aligned} E &= \frac{W}{Q} = \frac{Q - Q_R}{Q} \\ &= 1 - \frac{Q_R}{Q} \\ &= 1 - \frac{T_5 - T_2}{T_4 - T_3} \end{aligned}$$

And since, as already stated,

$$\frac{T_5}{T_4} = \frac{T_2}{T_3}$$

we get
$$\frac{T_5 - T_2}{T_4 - T_3} = \frac{T_2}{T_3}$$

therefore
$$E = 1 - \frac{T_2}{T_3}$$

Example Find the efficiency of the cycle in the preceding problem.

$$\begin{aligned} E &= 1 - \frac{T_2}{T_3} \\ &= 1 - \frac{521}{919.6} \\ &= 1 - .567 = .433 \end{aligned}$$

The work W done per cycle can be calculated from the efficiency, without knowing the heat rejected

$$E = \frac{W}{Q}$$

or
$$\begin{aligned} W &= E \times Q\quad \text{B.T.U.} \\ &= 779\,E \times Q\quad \text{ft. lb.} \end{aligned}$$

Examples. If the cycle discussed in the previous examples takes place in a cylinder of 12 in. diameter and 18 in. stroke, what will be the work done per cycle? If the engine makes 250 revolutions per minute, what will be its indicated horse-power?

Solution.

$$W = 779\ E \times Q \quad \text{ft. lb.}$$

$$Q = \frac{H}{n+1}\,(V_2 - V_1) \quad \text{B.T.U.}$$

$V_2 - V_1$ is the volume through which the piston moves in cu. ft., and is the product of the cross section area of the cylinder in sq. ft. by the stroke in ft.

$$\therefore \quad V_2 - V_1 = \frac{\pi}{4} \times \left(\frac{12}{12}\right)^2 \times \frac{18}{12}$$

$$= 1.178 \text{ cu. ft.}$$

$$\therefore \quad Q = 94.25 \text{ B.T.U.}$$

$$\therefore \quad W = 40.81 \text{ B.T.U.}$$

$$= 31791 \text{ ft. lb.}$$

Since this engine requires two revolutions to complete a cycle, the number of cycles per minute is only half the number of revolutions per minute; therefore the work per minute

$$= W \times 125 \quad \text{ft. lb.,}$$

and the horse-power $= \dfrac{31791 \times 125}{33000}$,

$$= 120.4 \text{ I.H.P.}$$

EXAMPLE FOR PRACTICE.

(a) A gas engine using the Otto cycle has 25 per cent clearance and takes in its charge at 14.7 lb. per sq. in. and at 60° F. What is the pressure at the end of the compression?

Ans. 141.1 lb. per sq. in. abs.

(b) What is the temperature at the end of compression?

Ans. 539° F.

(c) If the charge consists of 1 part of gas to 9 parts of air and the heat of combustion of the gas is 600 B.T.U. per cu. ft. what is the temperature at the end of explosion? Ans. 4258° F.

(d) What is the pressure at the end of explosion?

Ans. 665.9 lb. per sq. in. abs.

(e) What are the pressure and temperature at the end of the expansion? Ans. 69.4 lb. per sq. in. abs. 1997° F.

(f) What is the efficiency of the cycle? Ans. .479.

(g) If the cylinder diameter is 18 in. and the stroke is 24 in., and the engine makes 150 revolutions per minute, what is the I.H.P.? Ans. 180 I.H.P.

An examination of the equation for the efficiency of the Otto cycle,

$$E = 1 - \frac{T_2}{T_3}$$

brings out certain important results. The efficiency is seen to depend only on the ratio of the temperatures at the beginning and end of the compression, and not at all upon the temperature and pressure at the end of explosion. Since the ratio of the temperatures at the beginning and end of compression depends only upon the ratio of compression, and since further, the charge is always compressed till it occupies the clearance volume, the efficiency is seen to depend only upon the percentage clearance. In other words, in engines with the same percentage clearance using the Otto cycle, the percentage of the heat liberated in the cylinder that is converted into work is always the same whatever be the size of the engine or the strength of the charge. The effect of the clearance on the efficiency is exhibited in table I, where it is seen that the smaller the clearance the greater is the efficiency of the engine. The pressures at the

TABLE I.

Percentage Clearance of Otto cycle engine.	Pressure at the end of compression lb. per sq. in. abs.	Efficiency of Otto cycle.	Efficiency of cycle with increased expansion, but with the same compression pressure as the Otto cycle.
20	183.3	51.6	60.9
25	141.1	47.9	58.4
30	115.4	44.8	55.
35	98.	42.1	52.5
40	85.5	39.8	50.4

end of compression are also given in the table, and are calculated on the assumption that the atmospheric pressure is 14.7 lb. per sq. in. abs.

OTTO CYCLE WITH INCREASED EXPANSION.

The pressure at the end of expansion is seen in the example worked out to be 89 lb. per sq. in. abs. In ordinary practice it is commonly found to be from 50 to 60 lb. abs. It is evident that if the gas were permitted to expand further it would do more work and consequently would increase the efficiency of the cycle. The indicator card, Fig. 19, shows one method used for obtaining more expansion. The charge enters at atmospheric pressure from 1 to 2, when the admission is cut off. The piston continues moving forward to the end of its stroke, but as no more admission takes place the charge expands adiabatically to 3, while its pressure falls. On the return stroke the charge is compressed adiabatically, retracing the expansion path along 3 2 and continuing till the whole charge is compressed into the clearance space at 4. The rest of the cycle is unchanged. The diagram 1 2 4 5 8 2 represents the ordinary Otto cycle, and the shaded area 8 6 7 2 represents the increase in work due to the increased expansion.

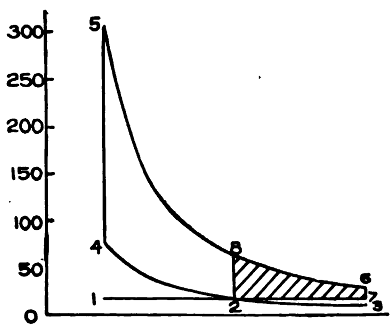


Fig. 19.

The efficiency of this cycle can be easily calculated and the results of such calculations are given in table I. They are made on the assumption that the charge is admitted for only one-half the stroke and that the heat combustion is 80 B.T.U. per cu. ft. of the charge. An inspection of the table shows the increase in efficiency which results from the increased expansion for engines which have the same pressures at the end of compression and indicates that in order that a gas engine of this type should be of high efficiency, it should compress the charge to a high pressure, and then should expand the products of combustion to a volume considerably in excess of the original volume of the charge.

THE IDEAL AND THE REAL OTTO CYCLES.

The calculations in the preceding pages are made on the assumption that the gas engine follows the Otto cycle exactly, in

which case the engine is called an *ideal* engine. The *real* engine does not exactly follow the Otto cycle because of certain practical difficulties. Differences between the real and the ideal engines occur in each part of the cycle. During admission (Fig. 20, line 1 2) the pressure in the cylinder is actually a pound or more below the atmospheric pressure, that difference being necessary to open the air admission valve (when automatic), and to cause the air to flow in with sufficient velocity. The charge, moreover, is heated by contact with the cylinder walls and with the hot gases remaining in the clearance. The compression is not adiabatic because it occurs in a cast iron cylinder which takes heat from the gas while it is being compressed and so makes the final temperature and pressure less than that calculated on the assumption of adiabatic expansion. The difference, generally, is not very great.

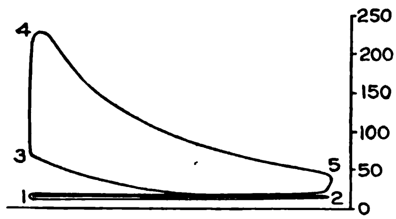


Fig. 20. Indicator Card from Otto Cycle Engine.

The explosion in the real engine is neither instantaneous nor complete. It approximates more closely to the ideal explosion when the compression is considerable and when the explosive mixture has only a small excess of air present. With weaker mixtures the explosion becomes slower and less complete, as shown in Fig. 21, till, with the weakest explosive mixture, the process is really one of slow combustion taking place throughout the whole of the expansion period, and some of the charge may be still unburned when exhaust takes place.

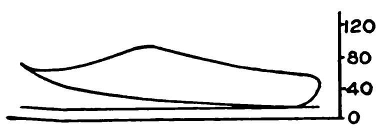


Fig. 21. Indicator Card with Weak Mixture.

Even under the best conditions the rise of temperature, and consequently of pressure, during the explosion is only about six-tenths of that occurring in the ideal engine. This, it will be seen, makes the power of the real engine considerably less than that of the ideal. The water jacket around the cylinder, without which the cylinder would be too hot to be properly lubricated, is one of the

important causes of the difference between the real and ideal cycles. as the jacket absorbs usually about forty per cent of the total heat of the combustion.

The expansion curve is above the adiabatic in real engines because the cylinder walls that have been heated by the explosion give back some heat to the gases and also because the combustion still continues and liberates more heat. This last effect is especially marked when the explosive mixture is weak.

Finally, the exhaust, as in the steam engine, begins a little before the end of the expansion stroke so as to give plenty of time for the escape of the gases, and the pressure in the cylinder during the exhaust stroke is necessarily higher than that of the atmosphere into which the gases are rejected.

The total effect of all these differences between the real and the ideal engine is that the work done in an actual engine in good condition is only from five-tenths to six-tenths of that which the ideal engine would do, and the efficiency of the real engine is only from five-tenths to six-tenths of that of the ideal engine.

Example. What are the probable actual efficiency, horse-power and gas consumption of the engine whose ideal performance has been worked out in the preceding examples? Assume the real engine to have $\frac{6}{10}$ the efficiency of the ideal engine.

The ideal efficiency was found to be .433.

$\therefore$ The probable real efficiency $= .6 \times .433 = .26$.

The ideal horse-power was found to be 120.4,

the probable real H. P. $= .6 \times 120.4 = 72.2$.

The gas consumption is expressed in cu. ft. per I.H.P. per hour. In the ideal engine the volume of gas taken in per cycle was

$$\frac{V_2 - V_1}{n + 1} = \frac{1.178}{8} = .147 \text{ cu. ft.}$$

The number of cycles per minute was 125.

$\therefore$ the gas used per minute $= .147 \times 125$ cu. ft.

$= 18.4$ cu. ft.

$\therefore$ the gas used per hour $= 18.4 \times 60$ cu. ft.

$= 1104.$ cu. ft.

And the probable real I.H.P. is 72.2.

$\therefore$ the gas used per I.H.P. per hour $= \frac{1104.}{72.2} = 15.3$ cu. ft.

EXAMPLE FOR PRACTICE.

What are the probable actual efficiency, I.H.P. and gas consumption of the engine whose ideal performance has been worked out in the previous examples for practice.

Answers: .287 efficiency.
108 I.H.P.
14.71 cu. ft. gas consumption.

Ignition. For satisfactory action of a gas engine the ignition of the explosive mixture must be certain and must occur at a definite predetermined time. In *timing* the ignition it has to be recognized that the explosion is not instantaneous but requires the lapse of a not inconsiderable period of time before the maximum pressure is reached. The actual duration of the explosion depends on the strength of the explosive mixture and on the amount of compression to which it is subjected.

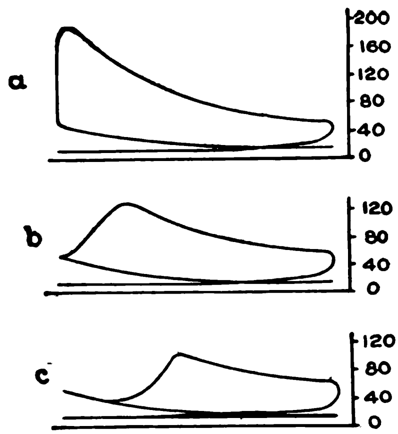


Fig. 22.

The ignition should have *lead*, that is, should begin a little before the end of the return or compression stroke, when the crank is about 15° from its dead center, so that the maximum pressure is reached when the crank has just passed the dead center. The indicator card, *a*, Fig. 22, is with properly timed ignition. If the ignition is later than this, indicator cards similar to *b* or *c* will be obtained, and the engine will do less work and be less efficient. If the ignition is too early, the maximum pressure will be obtained (Fig. 23) before the crank has reached its dead center and will tend to reverse the engine. This causes great shock to the engine, its rapid deterioration and low-

Fig. 23.

ered efficiency. The immediate external evidence of too early or premature ignition, from whatsoever cause, is a violent pounding noise in the engine.

Two methods of ignition are in common use in engines using the Otto cycle. The first is by bringing the explosive mixture into contact with some surface which is kept at a temperature sufficiently high to cause ignition; the second is by means of an electric arc. A hot tube is the common device when the first method of ignition is used. The tube E (Fig. 24) is closed at the upper end and communicates at its lower end through the port B with the cylinder A. It is heated by an external flame from the Bunsen burner C, and is maintained at a full red heat. The chimney around the tube is lined with asbestos and keeps the flame in good contact with the tube. During the admission stroke the tube is filled with products of combustion at atmospheric pressure remaining from the previous explosion. As

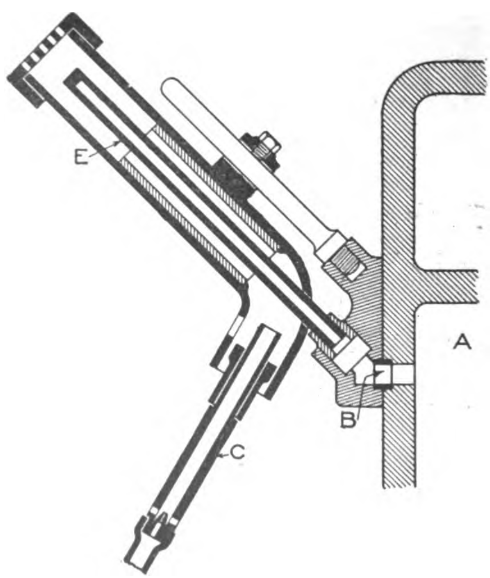
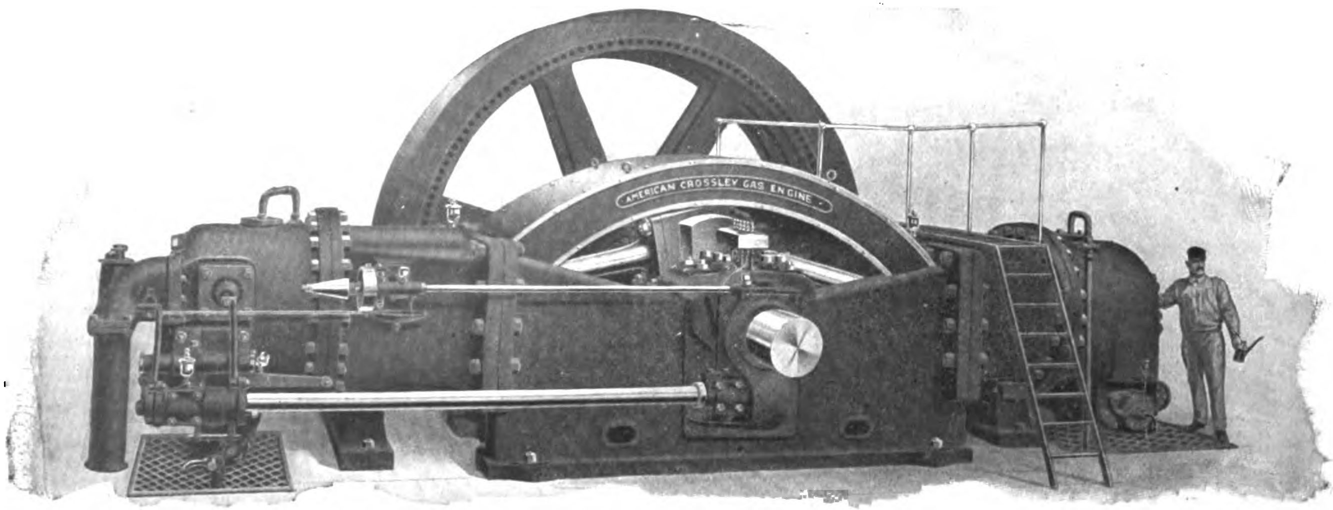


Fig. 24. Hot Tube Igniter.

compression goes on, the non-explosive products of combustion are crowded into the upper part of the tube while part of the explosive mixture in the cylinder is compressed into the lower part of the tube. The length of the tube and the position of the flame are adjusted by experiment so that the explosive charge will just reach the hot portion of the tube and be ignited at the moment when ignition is desired. Shortening the tube makes the ignition come earlier. With this device the actual time of ignition is not very definite. It depends on the temperature of the tube, the position of the Bunsen flame, the strength of the



AMERICAN CROSSLEY GAS ENGINE.
Power and Mining Machinery Co.

mixture and the amount of compression. As these last two quantities are purposely varied by the governor in some engines, irregular timing would result from its use in such cases.

The irregularity of timing with the hot tube igniter can be partly remedied by the use of a *timing valve.* The timing valve B (Fig. 25) is held on its seat by a spiral spring D until ignition is desired, when by a movement of the bell crank lever E the valve opens and the compressed charge in the cylinder A gets access to the hot tube C. The valve B is kept open till the end of the exhaust stroke. The tubes are preferably made of nickel alloy or of porcelain, but the latter is very brittle and apt to break when being fastened in place. Iron tubes are used sometimes, but they burn out rapidly and are unreliable.

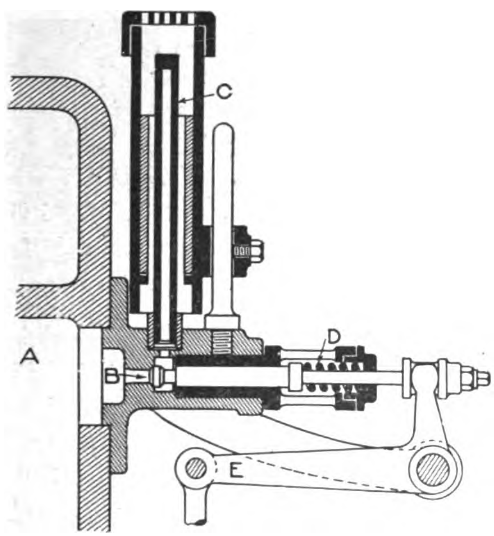


Fig. 25. Hot Tube Igniter with Timing Valve.

Even when provided with a timing valve the hot tube does not give very satisfactory ignition; and, moreover, some time is consumed in heating the tube before the engine can be started. Accurate timing can be obtained best by electric means, and *electric ignition* is consequently used more than any other. The method is to make a spark pass at the instant when ignition is desired between two terminals situated in the clearance space of the engine. The most common way of forming the spark is to separate two contact points through which a current has been flowing. An electric arc will then pass between the separating contact points. In order to ensure that the temperature of the arc is high enough and its duration is sufficient to ignite the explosive mixture through which it passes, a *spark coil* is generally inserted in the circuit. A spark coil con-

sists merely of a bundle of soft iron wires surrounded by a coil of insulated copper wire, through which the current goes. The contact points of the igniter must be brought together to re-establish the current before another spark can be obtained. A device of this nature is known as a *make-and-break* igniter; and when the contact points do not slide across one another, it is called a *hammer break* contact.

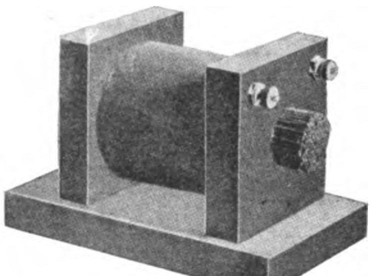


Fig. 26. Spark Coil.

One of the common forms of hammer break igniter is illustrated in Fig. 27, which shows an igniter plug removed from the cylinder head. The movable electrode *b* is at the end of an arm which is fastened to the spindle *e*. When the interrupter lever *d*, which is loose on the spindle *e*, and is connected to it through a coiled spring, is lifted by an arm from the cam shaft of the engine, it rotates the spindle *e* so as to bring *b* into hard contact with the stationary and thoroughly insulated electrode *a*. This completes a circuit and permits a current to flow from *a* to *b*. When ignition is desired the lever *d* is tripped and flies back, carrying with it the shaft *e*, abruptly breaking the contact and causing an electric arc to form between *a* and *b*. The contact points are generally made of platinum, as this does not oxidize or corrode, but other metals are also used. The passage of the spark takes minute particles of the material from one terminal and deposits them on the other, the action following the direction of the current. By reversing the direction of the current, the material may

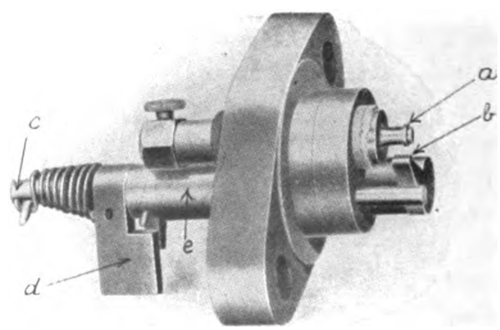


Fig. 27. Otto Engine Igniter Plug.

be returned to the terminal from which it was taken, and the durability of the contact points considerably increased.

The current is generally taken from a primary battery, consisting of about five cells. The Edison-Lalande cell, made up of two zinc plates and a plate of compressed copper oxide immersed in a strong solution of caustic soda, is perhaps the most largely used. Other sources of electricity can be used. Current is sometimes taken from a direct current lighting or power circuit, but this is objectionable because the circuit is grounded every time the igniter terminals are in contact. The practice is growing of using a small special dynamo for the exclusive purpose of supplying the current for ignition. This makes the ignition spark more certain and of more uniform strength than when a battery is used, as the latter deteriorates and weakens with use.

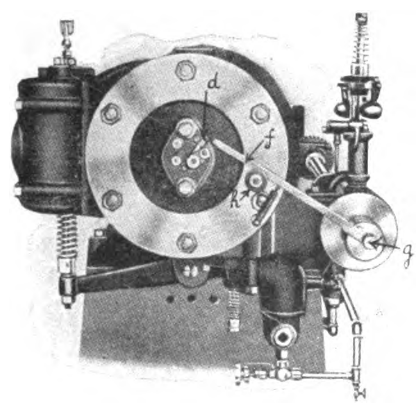


Fig. 28. Igniter Gear of Root and Van Dervoort Engine.

A make-and-break contact is sometimes obtained by sliding one contact point over the other until it slides off completely. This is known as a *wipe break*. The method ensures a good contact, produces a very hot spark, keeps the contact points clean, but wears them out quite rapidly. Provision must be made for adjustment, otherwise the timing will alter with the wear of the points. The rubbing surfaces can be of iron.

The igniter gear of an engine with hammer break ignition is shown in Fig. 28. The igniter rod *f*, which is supported on the reel *h*, receives a reciprocating motion from a crank *g* at the end of the side shaft. During the exhaust or admission stroke the end of the rod *f* comes in contact with the interrupter lever *d* (compare with Fig. 27) and establishes the contact of the electrodes. The vertical component of the movement of the end of the rod *f* sets free the lever *d* at the moment when ignition is desired.

A switch (Fig. 29) should always be included in the electric circuit and should be thrown out when the engine is not running, so as to prevent the short-circuiting and consequent exhaustion of the batteries.

Another way of obtaining electric ignition is known as the *jump spark* method. In this system the terminals are stationary, generally from one-sixteenth to one-eighth of an inch apart, and the spark is made to spring across the gap between them by putting the terminals in the secondary circuit of a Ruhmkorff or *induction coil.* This coil consists of a core of soft iron wire around which is wound a relatively coarse insulated wire, the *primary circuit*, through which the current from the source of energy flows. A relatively fine insulated wire coil, the *secondary*

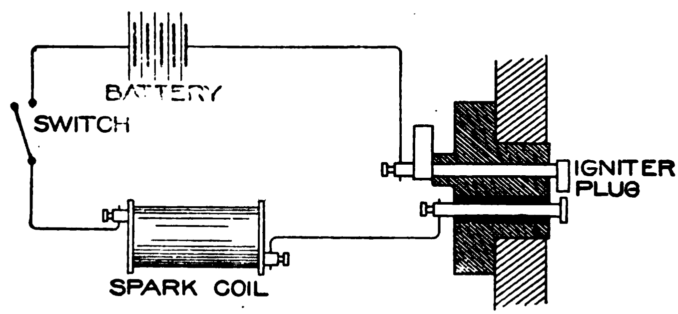


Fig. 29. Diagram of Igniter Circuit.

circuit, is wound around the primary coil, but has no metallic contact with it. If the current flowing through the primary circuit is varied in strength, it creates or induces a current in the secondary circuit. Generally the Ruhmkorff coil is provided with a magnetic vibrator (similar to that used in an electric bell), which makes and breaks the primary circuit with great rapidity and induces a considerable alternating current in the secondary circuit. If the two ends of the secondary coil be brought close to one another, but not quite in contact, a spark will jump across the gap at each make and break of the primary current, the spark at the break being the more powerful. For ignition of the explosive mixture in a gas engine it is not necessary to use a vibrator; the cam shaft of the engine breaks the primary circuit at the instant when explosion is desired. The spark passing on the subsequent

remaking of the primary circuit is not strong enough to ignite the charge. The connections for jump spark ignition are shown diagrammatically in Fig. 30. The primary circuit is shown there as being completed through a cam on the side shaft of the engine. As soon as the side shaft has moved from the position shown, the contact with the upper flat spring is broken and the primary current is interrupted, thereby inducing sufficient current in the secondary circuit to make a spark pass across the air gap between the terminals of the spark plug. These terminals are completely insulated, so that the only path for a current between them is across the air gap.

The jump spark method has as its great advantage the absence of moving parts inside the cylinder. This is offset by the fact that the spark is liable to fail as a result of the formation of

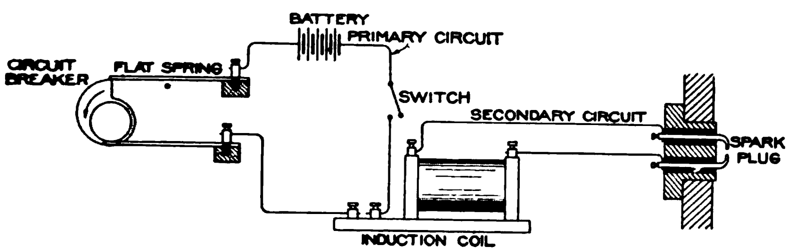


Fig. 30. Diagram of Jump Spark Igniter and Connections.

deposits of rust or corrosion on the points, the liability to this being much greater than in either of the make-and-break methods. The difficulty of obtaining satisfactory insulation is also greater.

Governing. The governing of an engine means the control of the power which it is developing so that its speed is maintained practically constant. If the engine develops more power than is required, the engine will speed up; if the power delivered to the crank shaft is less than the resistance there, the engine will slow down. The governing of a gas engine, like that of the steam engine, is effected by utilizing small variations of engine-speed resulting from change of engine load. The controlling mechanism, or the governor proper, does not differ from that used on the steam engine, but there is a considerable difference in the way in which it controls the work done by the engine. There are two general methods in use in gas engines for varying the power; one by vary-

ing the number of explosions or impulses per minute, which is known as the *hit-and-miss* system, and the other by varying the magnitude of the impulse while keeping the number per minute constant, which may be called the *variable impulse* system.

The Hit-and-Miss System. The omission of the explosion or impulse can be obtained in several ways. The most common method is to keep the gas admission valve closed so that air alone is taken in during the admission stroke, and consequently there is no explosion. A method of accomplishing this is to be seen in Fig. 31, in which a loaded centrifugal governor is shown driven by bevel gearing from the cam shaft. In the position shown, the gas admission cam *d* will come under the reel *c*, and will start to lift it at the beginning of the admission stroke. The reel *c* is loose on a spindle at the end of the horizontal lever *e*, and the vertical rise of the spindle due to the action of the cam opens the gas valve by a system of levers not shown in the figure. If the engine speeds up, the rise of the governor balls raises the sleeve on the governor spindle, lifts the horizontal arm of the bell crank lever fulcrumed at *a* and shifts the forked end *b* of the vertical arm to the right, carrying the reel *c* with it, so that the cam no longer engages it and no gas is admitted. When the speed comes down to the normal speed, the reel is moved back and the admission of gas again takes place. This method is open to the objection common to all the hit-and-miss methods that it makes the speed of the engine very irregular at any other than full load. Even at full load, with the Otto cycle occurring in a single acting cylinder, there is only one motive stroke or impulse in four strokes instead of one every stroke as in a double acting steam engine. If the engine governs by the hit-and-miss method and is running at half load, half the explosions will be omitted and there will be but one motive stroke in eight; at one-third load, there is but one motive stroke in twelve; and at

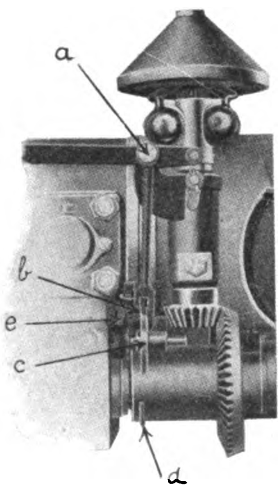


Fig. 31. Governor of Otto Engine.

quarter load, one in sixteen. Running at quarter load, the engine will be speeded up during the motive stroke and will slow down during the succeeding fifteen strokes till it gets to normal speed again. The actual variation in speed at low loads can be reduced by the use of heavy fly wheels, but with this method of governing it is too great for use when close regulation is necessary, as for electric lighting. There is an incidental advantage in the use of this method in that, during the idle cycles, the cylinder is flushed out by the *scavenging* charge of air, which makes the next explosion more powerful.

The omission of an explosion is sometimes effected in engines which have an automatic admission valve by the action of the governor in keeping the exhaust valve open throughout the cycle. The free communication between the cylinder and the outside through the exhaust valve prevents the pressure in the cylinder from falling sufficiently below the atmospheric pressure, during the admission stroke, to cause the inlet valve to open. The cylinder contains only products of combustion, substantially at atmospheric pressure, so long as the exhaust is open, and consequently no explosion can occur.

The Variable Impulse System. The amount of work done in a given gas engine depends on the strength of the charge, on its amount, on the timing of the ignition, and on several other factors. The engine can be governed by the variation of *any one* of these, and the three specifically mentioned are all in regular use for this purpose.

If the governing is effected by *varying the strength of the charge*, the control has to be such that the mixture is always an explosive one. With each kind of gas used in an engine there are both higher and lower limits to the amount of air with which it may be mixed if it is to remain an explosive mixture. If the ratio of air to gas should be outside these limits, the mixture sent to the exhaust would be unburned and valuable gas would be lost. Conseqently, if the engine goes above normal speed when admitting the weakest explosive mixture, the power of the engine has to be further reduced by omitting the admission of gas entirely. In Fig. 32 is shown a device for governing in the manner just described. The governor *d* is driven from the cam shaft *c* through

the bevel gears shown in section. Gas is admitted by raising the end of the lever on which is a reel *b* similar to *c* in Fig. 31. The sleeve *a* is free to slide on a feather on the cam shaft *c*, its exact position being controlled by the governor through the bell-crank lever *e*. On the sleeve *a* is a series of cams of the same throw but of different circumferential lengths. The duration of the admission of gas is varied by shifting the sleeve so as to bring different cams into engagement with *b*. In the position shown the engine is above normal speed, and the sleeve is at extreme position to the right and no gas is being admitted. As the speed of the engine falls, the sleeve travels to the left, admitting gas for a definite period for each engine speed. With full load on the engine, the reel engages with the longest cam and the strongest mixture is admitted to the cylinder.

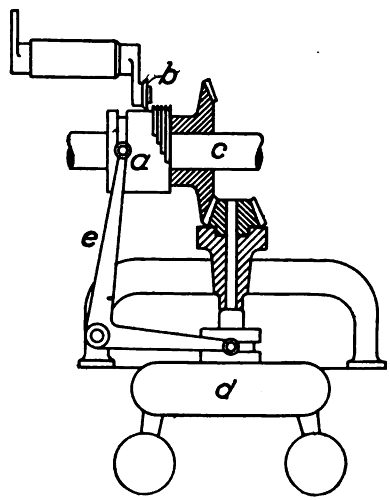


Fig. 32. Diagram of Governor.

With this method of governing, the same amount of the mixture is always taken into the cylinder, and consequently the pressure at the end of compression is always the same. The explosion, however, becomes weaker as the mixture is "leaner" and requires a longer time for its completion. A comparison of the areas of Figs. 20 and 21 shows the effect of a weaker mixture on the power of the engine.

It is found in practice that there is a certain strength of the explosive mixture which gives the most economical running of the engine. It is obviously desirable to run the engine with a mixture of this strength, and that can be done when a hit-and-miss governor is used. When it is desired to have an impulse every cycle, a constant strength of mixture can be maintained if the power of the engine is controlled by varying the *amount of the mixture* taken in. An example is shown in Figs. 33 and 34 of the actual mechanism used for this purpose. Gas from the passage

G enters a port in the cylindrical valve A and meets air which enters from D through similar ports. The mixture passes out of the valve through a large port near the top and goes through C to the cylinder when the inlet valve D is open. The relative amounts of gas and air are regulated by the two levers H H, which are connected to entirely independent cylindrical shells inside the valve A and which can rotate them so as to cover up more or less of the lengths and therefore of the areas of the gas and air ports respectively. With the two levers in constant positions the areas for admission of gas and air to the cylindrical valve A will be fixed, and consequently the strength of the mixture will be constant. The actual amount of the mixture entering the cylinder is controlled by the governor B, which works an internal cylindrical valve in such way as to throttle the discharge port of the valve A when the speed increases.

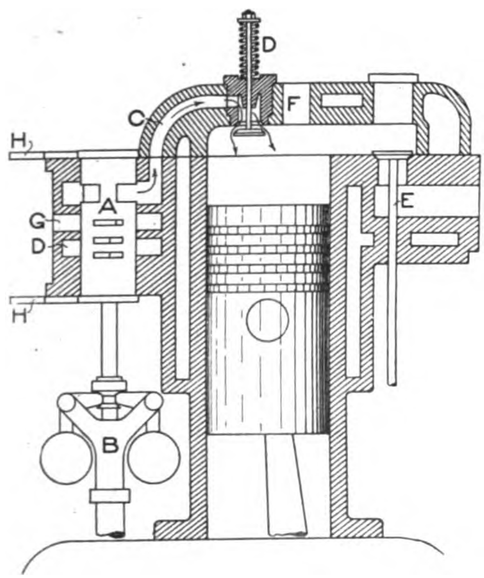


Fig. 33. Mixing Valve of Westinghouse Engine.

This method of governing permits a perfect adjustment of the work done in the cylinder each cycle, and consequently gives more uniform speed of the engine than any of the methods so far described. The throttling of the mixture imposes extra work upon the engine during the admission stroke, as the piston has to move out with a vacuum behind it. At the end of the admission the pressure in the cylinder will be less and less as the load on the engine becomes smaller, and consequently the pressure in the cylinder at the end of compression is less as the load decreases. With decreased compression the combustion of the mixture is slower. This is well shown in Fig. 35, which gives a series of indicator

cards taken at different loads from an engine using a strong mixture and a throttling governor.

Another method of accomplishing the same result is to admit a mixture at atmospheric pressure for part of the admission stroke only, the duration of the admission being determined by the governor. This method of governing gives an indicator card similar to Fig. 19. The difference between an engine governing in this way and one governing by the throttling method is similar to that between a Corliss steam engine and a throttling steam engine. The advantage of *cut-off* governing is in the decreased work done by the engine in drawing the charge into the cylinder. The use of a partial charge, whether obtained by throttling or by cutting-off, permits the expansion of the exploded mixture to a lower pressure than is possible in an engine admitting a full charge and having the same pressure at the end of compression. This is the practical method of obtaining the increased expansion, the advantage of which has been already pointed out.

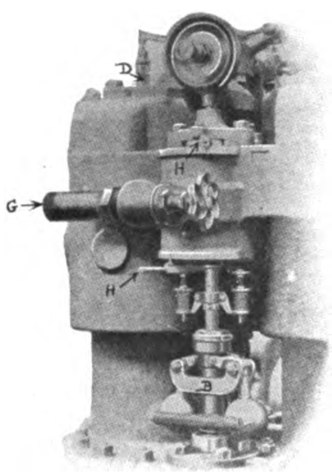


Fig. 34. Governor of Westinghouse Engine.

When economy is not of the greatest importance, as, for instance, in automobile practice, the power of the engine may be controlled by *varying the point of ignition*. It has been shown already (Fig. 22) that the power of the engine decreases as the lead of the ignition becomes less. If the ignition occurs after the beginning of the stroke, the lead is said to be negative, and the power is greatly decreased. If the lead is increased (Fig. 23), there still results a decrease of power. The

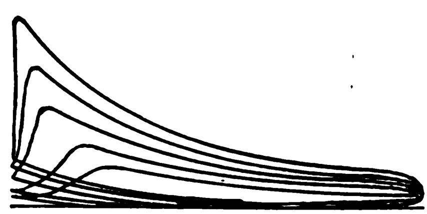


Fig. 35.

control of the power by varying the ignition is always uneconomical, but the method is one of extreme simplicity.

Starting. A gas engine will not start itself in the way a steam engine does when steam is turned on. It is necessary to get the engine in motion by means of some special source of power before it can take up its normal cycle of operations. Generally this special source of power is not adequate to get the engine moving rapidly when it is connected to any considerable load; it is always preferable and generally necessary to throw the load completely off the engine till it gets under way.

In the normal running of an engine the ignition of the charge occurs before the end of the back stroke, and if the time of ignition is kept the same when starting there is a danger, or often the certainty, that the high pressure of the explosion acting on the piston before the crank has got to its dead center, will overcome the inertia of the engine, which is small because of its low speed, and will reverse its direction of rotation. If the starting power is small, the ignition has to be retarded by some special device so that it will not occur till after the crank has passed its dead center—that is, there must be negative lead. An example of a device for retarding the ignition is given in Fig. 36. The igniter rod A (compare with *f*, Fig. 28) which is worked by a crank on the side shaft B, is supported during normal running on the reel C, which is loose on the fixed spindle D. In the position shown it is just about to trip the interrupter lever E on the spindle which moves the movable electrode. When starting, the reel C is slid along the spindle D so that the igniter rod A rests, as shown in the dotted lines, directly on D, consequently the tripping occurs so much later.

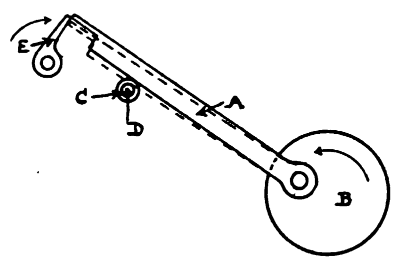


Fig. 36

There are several general methods of starting gas engines. If the engine is small, not exceeding 10 H. P., and can be disconnected from its load, it is common to start it by turning it over by hand for a few revolutions till an explosive mixture is admitted and ignited. As it is difficult to pull the engine over when the charge

is compressed for the whole back stroke, most engines are provided with an extra exhaust cam which is put into action while starting, and which not only opens the exhaust valve during the exhaust period but also opens it again during the first part of the compression period, so that some of the explosive mixture is forced out of the cylinder and the amount of compression is decreased. The explosion of this diminished charge after the crank has passed the dead point, starts the engine going, and after operation under these conditions for several cycles, the engine will come up to speed if it is not loaded heavily, and the compression and ignition may then be changed back to the normal running conditions.

With large engines it is impracticable to start by hand, and other devices have to be used. One of the most simple and certain is to start the engine by the admission of compressed air, which acts on the piston just as steam does in a steam engine. This method is especially desirable in an engine with several cylinders, in which case one cylinder is used as a compressed air cylinder to run the engine till the other cylinders take up their normal cycle of operations; and then the compressed air is shut off and the first cylinder is put into normal action. If the engine has only one cylinder, it can be brought to a good speed by the admission of compressed air, and then, after the compressed air is shut off, it will continue to revolve by its own inertia until an explosive mixture is taken in and exploded.

An arrangement for starting a multicylinder engine with compressed air is illustrated in Figs. 3 and 37. A compressor (Fig. 37), which is driven by a belt from the engine, forces air into a storage tank and brings it to a pressure of about 160 lb. In case of need the compressor can be operated by hand. When the engine is to be started, the compressed air can be admitted to one of the cylinders. The cam B (Fig. 3) on the upper shaft is first thrown out of action by a special device, so that the inlet valve J cannot open. The hand lever on the outside of the crank case near the cam A is thrown over, putting the ordinary exhaust cam A out of action, but bringing into action a double cam which keeps the exhaust valve E open throughout every up-stroke of the engine. Another cam on the same shaft is brought into action at the same time, and operates a starting valve (not shown) on the

pipe from the compressed air reservoir, admitting compressed air to the cylinder on every down stroke. The cylinder then acts as a compressed air engine till the explosions begin in the other cylinders, when the cams B and A are brought back to their normal positions and the starting cylinder functions normally. In other engines compressed air is admitted to the cylinder during the expansion stroke by manual operation of a special valve. After two or three admissions during successive cycles, the engine will attain speed enough to permit the opening of the gas valve and the commencement of the cycle.

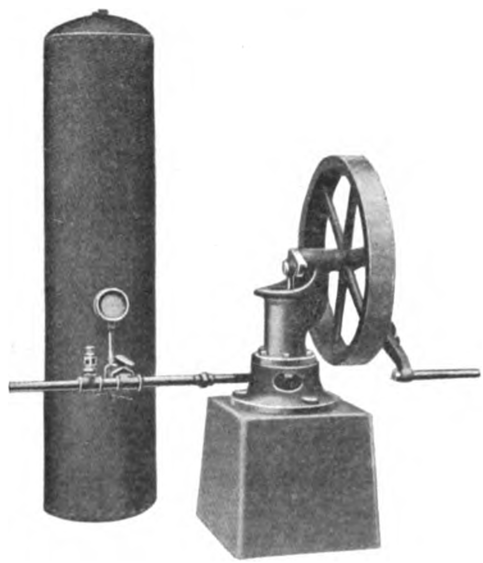


Fig. 37. Air Compressor.

With engines up to 100 H.P. a common method of starting is to ignite a charge which has been drawn into the engine by turning it over by hand. The engine is brought to the beginning of the expansion stroke, and a definite amount of gasoline is put into a cup which connects with the cylinder through a valve which is opened. The engine is then pulled over till the piston has made half its forward stroke, air being drawn in and forming an explosive mixture with the gasoline which enters at the same time. The gasoline valve is then closed and the engine is turned quickly in the opposite direction, the charge is compressed as much as possible, and is then ignited. The ignition is brought about by tripping the electric igniter by hand, or by the use of a special detonator, or even, in some cases, by striking a match inside the cylinder by means of a special device. It is not possible with a loaded engine to compress the charge much by hand, so that this method is only applicable to engines of moderate size which can be disconnected from their starting load.

If the engine has to start under moderate load, it is generally necessary to supply the engine with a charge which has been compressed to a high pressure. This can be accomplished by setting the engine with the crank about ten degrees past the dead center on the expansion stroke, and then pumping an explosive mixture into the cylinder (Fig. 38) till the piston begins to move. At that instant the charge is ignited, and the work done by the expansion of the exploded charge will be enough to start the engine on its cycle of operations. Another method of accomplishing the same

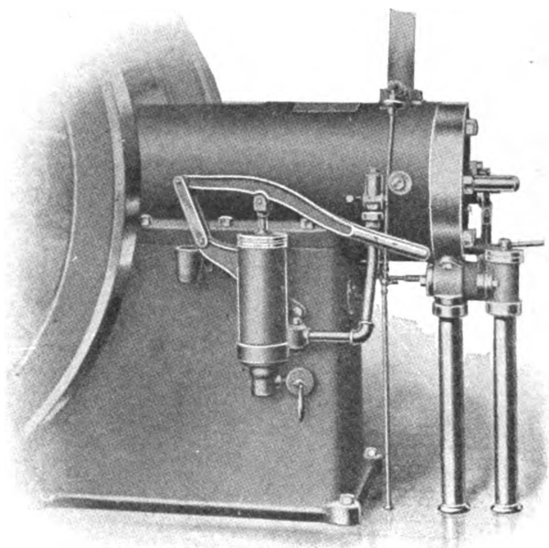


Fig. 38. Starting Gear of the Fairbanks-Morse Engine.

thing is to connect the cylinder E (Fig. 39) with a special starting chamber D. When the engine is being shut down, the special inlet valve A is lifted from its seat, so that at each suction stroke air is drawn through the chamber D by way of the valve F. The chamber D, the cylinder, and the connecting pipe are thus filled with pure air at atmospheric pressure. When the engine is to be started the gas cock C is opened and gas flows both into the chamber D and into the cylinder, a cock on the cylinder being opened. A pilot light burns across the opening above the valve F, and after a

short time a combustible mixture of air and gas issues and catches fire. If the cock C is then closed, the flow of the explosive mixture stops and the flame consequently shoots back past the valve F and ignites the mixture in D, closing the valve F against an upper face by the force of the explosion. The flame proceeds to the cylinder, the contents of which will have been compressed by the explosion in D, and causes an explosion there. In large plants a special starting engine is customary.

Water Jacket. In all the preceding sectional views of gas engine cylinders it will be seen that the cylinder barrel and the cylinder head have double walls and in every case provision is made for the active circulation of water through the space between the two walls. Without the use of a *water jacket*, or some equivalent device, the engine would be inoperative, because the high temperature to which the cylinder would be raised by the explosions would not only vaporize the lubricating oil and cause the rapid destruction of the cylinder, but also the entering mixture would be exploded before its time by contact with the hot metal. The necessity for effective cooling is greater in the larger engines; it is often necessary to water-jacket the exhaust valve in large engines that it may not be warped out of shape by the high temperature, and may not be hot enough to ignite the entering charge. The cooling arrangement for a balanced exhaust valve is shown in Fig. 14, the water entering the valve through the tube *b* and escaping after circulating at *c*. In some large engines the pistons also are water-jacketed. In very small engines

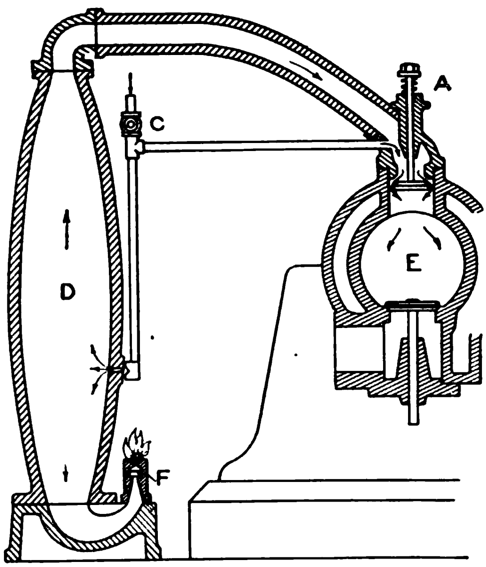


Fig. 29.

it is possible, when the engine is placed in a strong current of air, to replace the water jacket by a system of thin metal ribs (Fig. 40), or points, on the external surface of the cylinder. The current of air can be obtained either from a fan driven by the engine, or, as in bicycle motors, by the movement of the engine itself. When the engine is water-jacketed it is often practicable with small engines to use the same cooling water over and over again, and there is a distinct economy in so doing when the water must be paid for. The usual arrangement (Fig. 41) consists of a vertical galvanized iron water tank of considerable capacity connected at its bottom to the lower part of the jacket, and near its top to the upper part of the jacket. The water in the jacket being heated, rises and flows to the upper part of the tank, where it cools by contact with the air and with the sides of the tank. Cold water from the bottom of the tank flows to the cylinder jacket to take its place. A continuous circulation is maintained by the difference of density between the cold and the heated water. In large engines when a large amount of water must be circulated, this method is generally too cumbrous and the water is taken from some constant source of supply, such as the city mains. The piping and valves are always so arranged that it is possible to draw the water from the jacket.

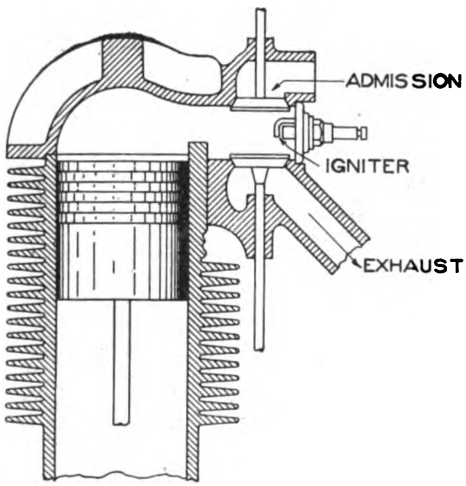
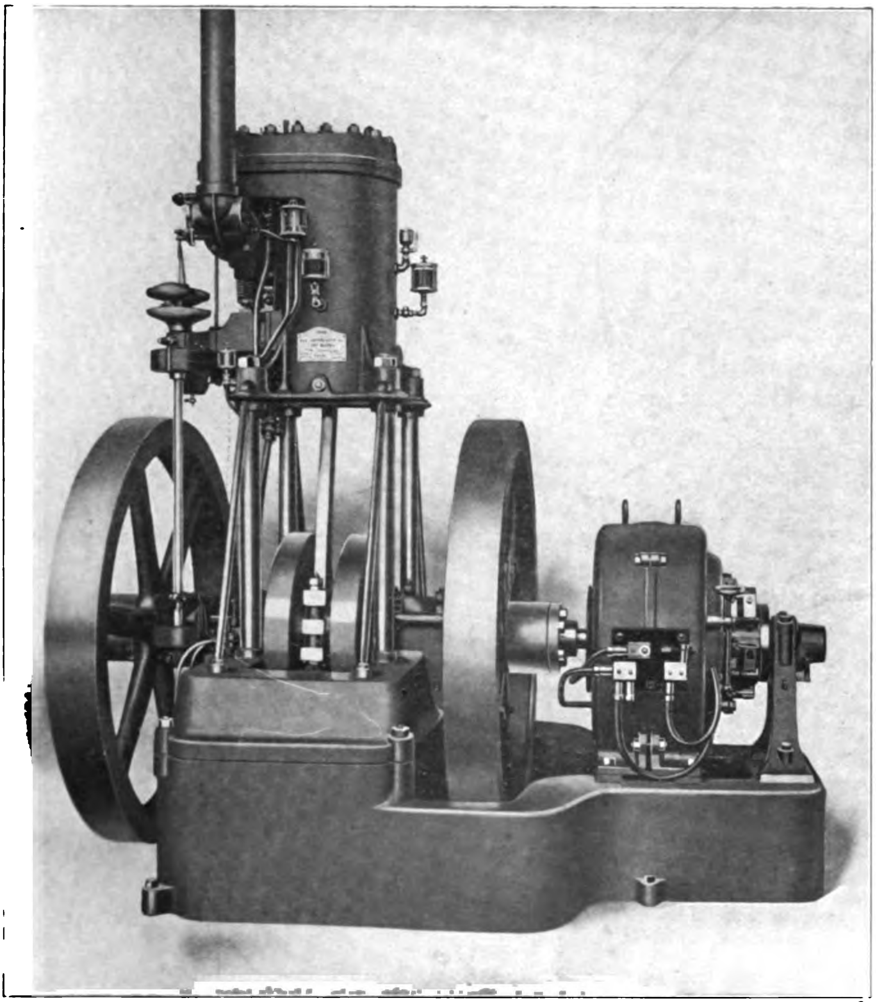


Fig. 40. Arrangement of Cylinder for Air Cooling.

The Explosive Mixture. The air used in the engine may be taken from the engine room or from the outside. The inrush of air to the air pipe makes a noise which is often objectionable in the engine room, but which can be greatly reduced if the air is taken from a large chamber, as in Fig. 10, where it is taken from the base of the engine.



15 KILOWATT, 250 LIGHT.
Secor Oil-Electric Generating Plant.

If the gas is taken from the city mains, the intermittent action of the engine in admitting gas will cause considerable fluctuation of pressure in the supply pipe, which is not only undesirable in that it makes variable the amount of gas admitted, but also causes flickering of any lights supplied from the same pipe. To reduce this fluctuation it is usual to insert in the gas supply pipe a rubber bag (see Fig. 11), which collapses partly during the admission stroke and fills out again during the other strokes. Any enlarge-

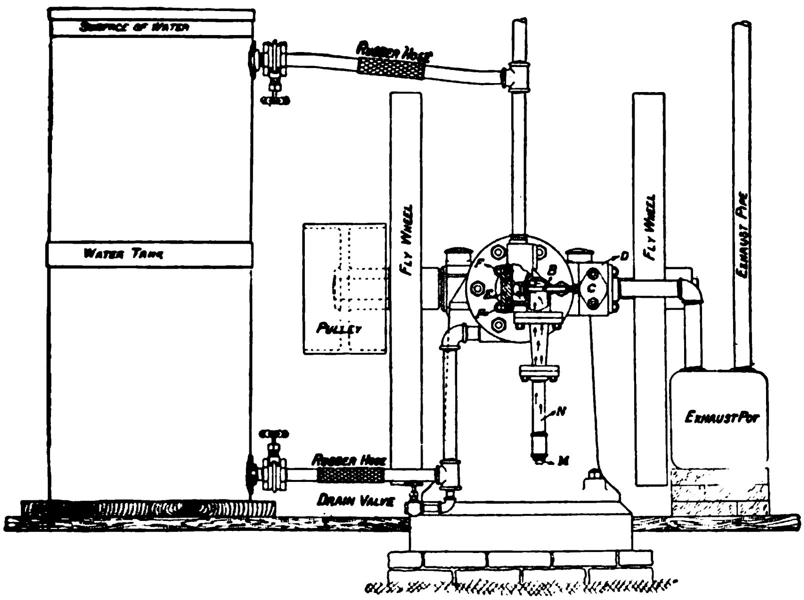


Fig. 41. Arrangement of Water Circulation for Jacket.

ment in the gas supply pipe will serve the same purpose, but the flexible rubber bag is more effective than a mere enlargement.

The air and gas should be mixed as thoroughly as possible on their way to the cylinder. This is satisfactorily accomplished if the air and gas have to pass through a common admission valve after they are mixed, as in Figs. 8, 10 and 33. The strength of the mixture is adjusted by throttling the gas supply, the air supply being left uncontrolled.

The Exhaust, if allowed to escape direct from an exhaust pipe of uniform cross section, is generally a source of annoyance by reason of the loud noise which it makes. This noise is greatly

reduced if the pipe discharges into an exhaust chamber or pot (see Fig. 41) before going to the air. The injection of water into the exhaust pipe is also useful in reducing the noise in large engines. To make the noise nearly imperceptible a good plan is to have the pipe discharge near the bottom of a pit filled with large stones.

Modifications of the Otto Cycle. Although the gas engine using the Otto cycle will give a higher efficiency than any steam engine, it is nevertheless desirable to increase its efficiency as much as possible. Its efficiency has been shown to depend on the amount of compression, and the obvious way of increasing the efficiency is to decrease the clearance and thereby increase the compression pressure. The amount of compression that can be used is limited by two considerations. The first is that it is not commercially practicable to construct engines which will work properly under very high pressures rapidly imposed by explosions. With an engine compressing the charge to 100 lb. pressure and using a strong explosive mixture, the pressure in the cylinder rises suddenly to about 350 lb., and this is at present about the practicable limit. If the explosive mixture is weak, the compression may be increased; with very weak mixtures a compression to 200 lb. is sometimes used, and results in a maximum pressure of about 300 lb.

The second objection to the use of high compression is that the rise in temperature of the mixture resulting from the compression may easily be sufficient to explode the mixture before the piston has reached the end of its stroke. Such pre-ignition of the charge, tending to force the piston back, gives rise to a great shock and is very destructive to the engine, besides reducing its efficiency, and is consequently to be avoided. Pre-ignition may occur even with low compression if any part of the clearance is not water-jacketed, or if there is any metallic projection into the clearance space. Such unjacketed parts, or projections, not being properly cooled, are liable to be raised to a temperature high enough to cause the ignition of the charge. This often forces water-jacketing of the exhaust valve and of the piston in engines of large size.

Another method of increasing the efficiency is by what is known as *scavenging* the cylinder. In the ordinary Otto cycle the

charge which is compressed consists of a mixture of fresh air and gas with the burned gases remaining in the clearance space from the previous cycle. If these burned gases are expelled from the cylinder by a charge of fresh air before the admission of the explosive charge, the force of the explosion and the efficiency are increased. The clearing out or scavenging of the cylinder with fresh air has been accomplished in several ways. The simplest method is by the use of an exhaust pipe of such length that the gases exhausting from the cycle with great velocity create a vacuum in the cylinder near the end of the exhaust stroke. This vacuum causes the automatic air admission valve to open and the consequent rush of air from the air valve to the exhaust port flushes out the cylinder, especially if the air and exhaust valves are on opposite sides of the clearance space. Occasional scavenging is obtained in engines governing on the hit-and-miss principle, each idle cycle flushing out the cylinder with the result that the succeeding explosion is of greater force than the normal explosion.

It has been pointed out already that the pressure at the end of the expansion in the Otto cycle is high, and that the efficiency of the cycle can be increased considerably if the gas is expanded more completely. Ordinary steam engine practice suggests that the more complete expansion can be obtained by *compounding*, but attempts so far to make a satisfactory compound gas engine have not proved very successful. The practical method of obtaining more complete expansion is to take into the cylinder a diminished charge. The two methods of accomplishing this have been discussed already. The only fundamental difference between engines using these two methods is that in one case the governor controls the amount of the opening of the admission valve, while in the other case it determines the instant at which the admission valve shall close.

One of the main objections urged against the Otto cycle is that it requires two revolutions of the engine for its completion, so that the expansion or motive stroke comes but once in four strokes. There results from this a very irregular driving effort, making large fly wheels necessary if the main shaft is to rotate uniformly, or else requiring the use of several engines working on the same shaft. The motive efforts can be made twice as frequent

if the cylinder is double acting, with admissions and explosions occurring on both sides of the piston. Many large engines are now being made double acting, but the practical troubles in keeping the piston, piston rod, cylinder and stuffing box cool enough for satisfactory working have prevented the use of double-acting cylinders in engines of small size.

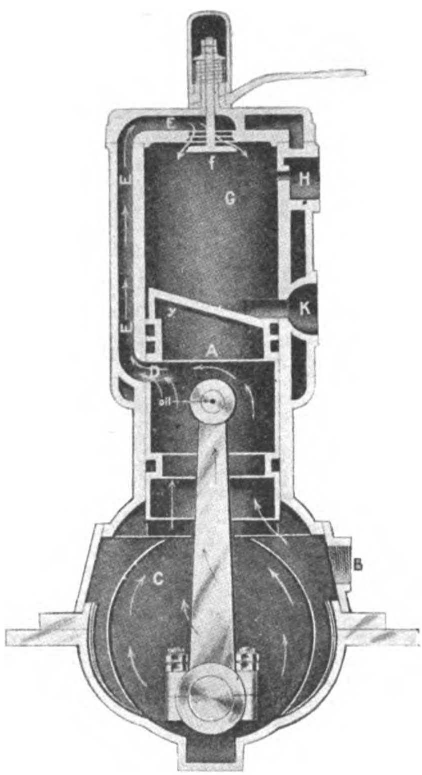


Fig. 42. Smalley Two-Cycle Engine.

An increased frequency of the expansion or motive stroke can be obtained by a slight modification of the Otto cycle which results in the cycle being completed in two strokes, and which is consequently called the *two-cycle* method. Engines using the two-cycle method give an impulse every revolution, and consequently not only give greater uniformity of speed of rotation of the crank shaft, but also develop nearly twice as much power as *four-cycle* or Otto cycle engines of the same size. Moreover, they are generally of great simplicity, having fewer valves than the four-cycle engines. An example is shown in Figs. 42 and 43 of a two-cycle engine of small size; Fig. 42 is a vertical section showing the piston at the bottom of its stroke, and Fig. 43 is a vertical section in a plane at right angles to the previous section plane and showing the piston at the top of its stroke. As the trunk piston A makes its upward stroke, it creates a partial vacuum below it in the closed crank chamber C, and draws in the explosive charge through B. On the downward stroke the charge below the piston is compressed to about 10 lb. pressure in the crank chamber C,

the admission through B being controlled by an automatic valve which closes when the pressure in C exceeds the atmospheric pressure. When the piston reaches the lower end of its stroke, it uncovers the exhaust port K and at the same time brings the admission port D in the piston opposite the by-pass opening E E E, and permits the compressed charge to enter the cylinder G through the automatic admission valve *f* as soon as the pressure in the cylinder falls below that of the compressed charge. The return of the piston shuts off the admission through E and the exhaust through K and compresses the charge into the clearance space. The charge is then exploded (Fig. 43) and the piston makes its down or motive stroke. Near the end of the down stroke, after the opening of the exhaust port K, the admission of the charge at the top of the cylinder sweeps the burned gases out, the complete escape being facilitated by the oblique form (Fig. 42) of the top of the piston. The engine is so designed that the piston on its return stroke covers the exhaust port K just in time to prevent the escape of any of the entering charge. The processes described above and below the

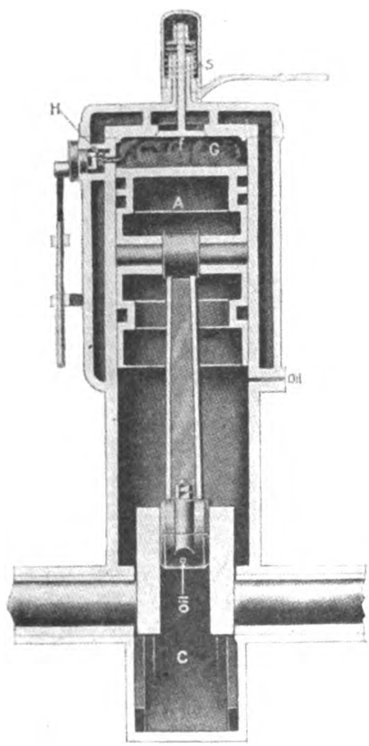


Fig. 43. Smalley Two-Cycle Engine.

piston are simultaneous, the upstroke being accompanied by the admission below the piston and compression above it, while the down stroke has expansion above the piston and a slight compression below it. The very short interval of time between the beginning of the exhaust and the admission of the new charge (which enters as soon as the pressure in the cylinder has fallen enough to permit the admission valve to open), makes premature ignition of the charge, or *back firing*, of not infrequent occurrence. If

the mixture is weak, or the speed is very high, so that the charge is still burning when the exhaust opens, or if the frequency of the explosions bring any part of the cylinder to a red heat, the charge will be ignited on entering, and the explosion then travels back through E E E to the crank case, which has to be made strong enough to resist it. In large engines the charge is compressed by a separate pump and not in the crank case. A modification of this engine makes the construction even more simple, so that the only valve on the engine is the automatic valve admitting the charge to the crank case. In this engine (Fig. 44) the series of operations is precisely similar to that just described. The only difference is in the by-pass connection E, which has no valve between it and the cylinder. The exhaust is made to open a little earlier than the admission, so as to make sure that the pressure in the cylinder shall have fallen below the pressure of the slightly compressed charge when the admission port opens. If the opening of the exhaust and admission ports were simultaneous, as in the engine just described, some of the exhaust gases would force their way through E to the crank case, igniting the charge there. The piston is so shaped that the entering charge is directed to the top of the cylinder, forcing out the burned gases before any of the charge can escape through the exhaust port.

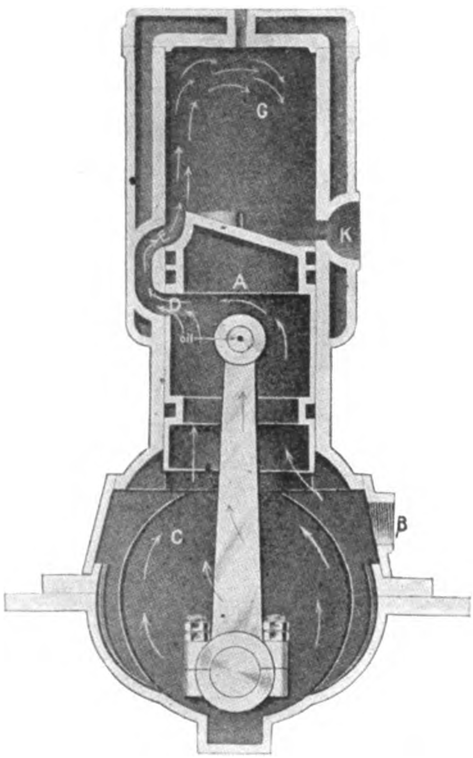


Fig. 44. Smalley Two-Cycle Engine.

The fact that the exhaust port is open while admission is taking place makes it always possible in a two-cycle engine that some of the charge may be lost through the exhaust. If the exhaust closes early, so as to diminish the probability of such loss, it will cause the retention in the cylinder of an unnecessarily large volume of burned gases, with consequent decrease in power and efficiency. The two-cycle engine may then be regarded as a modification valuable from the point of view of the more uniform turning movement, compactness and simplicity, but it is always likely to be inferior in efficiency. In some large engines the air and the gas are compressed separately; air alone is admitted at first, expelling the exhaust gases, and then the gas valve opens, admitting gas with the air. In this way the cylinder can be thoroughly scavenged and the exhaust be closed before any of the explosive charge reaches it.

Gas Engine Fuels. The fuels used in gas engines are very variable in origin, in composition, and in heat value. They consist almost entirely of various compounds of the chemical elements of carbon, hydrogen and oxygen, diluted with more or less nitrogen. In those regions where *natural gas* occurs, that fuel is used almost exclusively in the gas engine; but in most regions the gas has to be made either from solid or from liquid fuels. The use of liquid fuels will be considered later in connection with the discussion of the oil engine. In most towns of moderate size there is available *illuminating gas* made from coal. The illuminating gas is made by one of two processes giving either *coal gas* or *water gas*.

Coal Gas is made by heating the coal in a retort away from contact with the air, so that no combustion takes place. The hydrocarbon gases in the coal are driven off by the heat, and after undergoing various purifying processes, are collected in a holder. The non-volatile part of the coal remains as coke. The gas consists mainly of hydrocarbons and has a high heating value.

Water Gas is made from a non-gaseous fuel such as anthracite coal or coke, by an intermittent process. Air is blown through a bed of coal several feet thick until the coal is incandescent, the products of combustion being permitted to escape. Then a jet of steam is blown through the incandescent fuel, and is thereby broken up into its constituent elements—hydrogen and oxygen.

The oxygen combines with the carbon of the fuel to form carbon monoxide, CO; the hydrogen goes off unchanged. The passage of the steam quickly cools the coal, and air has to be blown through again. The only gas collected is that generated during the steam blow; it consists principally of hydrogen and carbon monoxide, and has a much lower heating value per cubic foot than coal gas. The whole of the coal is consumed in this process.

Both coal gas and water gas are excellent fuels for use in a gas engine, but as they have gone through certain processes for cleansing them and increasing their illuminating power, which increase the cost of the gas but do not add materially to its value for gas engine use, and since also the cost to the consumer is considerably greater than the cost of production, they are not economical fuels. Such fuels should be used only when the engine is very small or its operation very infrequent.

For engines of 50 H.P. or over, which are in regular operation, it is practically always more economical to generate the gas in a special *gas producer* than to use illuminating gas. In the gas producer either air alone, or generally both air and steam, are sent through a thick bed of coal. The oxygen of the air on first striking the zone of the incandescent coal combines with the carbon to form carbon dioxide, CO_2, but this on passing through the burning coal above, is reduced to carbon monoxide, CO, which escapes with the hydrogen and carbon monoxide resulting from the action of the steam on red hot coal, and with the nitrogen which came in with the air. The resulting gas therefore consists almost entirely of carbon monoxide, hydrogen and nitrogen. The large amount of nitrogen in the air (79 volumes in 100) makes the producer gas contain fifty per cent or more of that inert gas, and consequently gives it a low heat value.

A good example of a gas producer is shown in Fig. 45 under working conditions. The bed of coal, several feet thick, rests on a bed of ashes of about equal thickness, the ashes being supported on a solid circular table *a*. The blast pipe *b* terminates near the top of the bed of ashes, the blast being discharged radially so as not to concentrate the combustion. The blast is generally produced by a steam jet blower, but sometimes a fan blower is used. In the latter case steam is mixed with the air in the blast pipe so

as to keep down the temperature of the producer and to soften any clinkers that form. Fresh coal is supplied by a continuous automatic feeding device on top of the producer, which spreads the coal in a uniform layer over the upper surface. In many producers the coal is merely dumped in from above at intervals, and has to be spread by hand. The intermittent charging has the disadvantage that it causes considerable variation in the condition of the fire, and consequently in the composition of the gas generated. The bed of ashes is maintained of the desired depth and the surplus ashes removed by rotating the grate *a* by means of gears worked through the crank *c*. As the grate is placed at some distance below the conical casing or *bosh*, the ash discharges uniformly around its periphery when it is revolved. This causes a uniform settling of the bed of ash, and also lets the bed of fuel settle so as to close up any channels in it which have been formed by the blast.

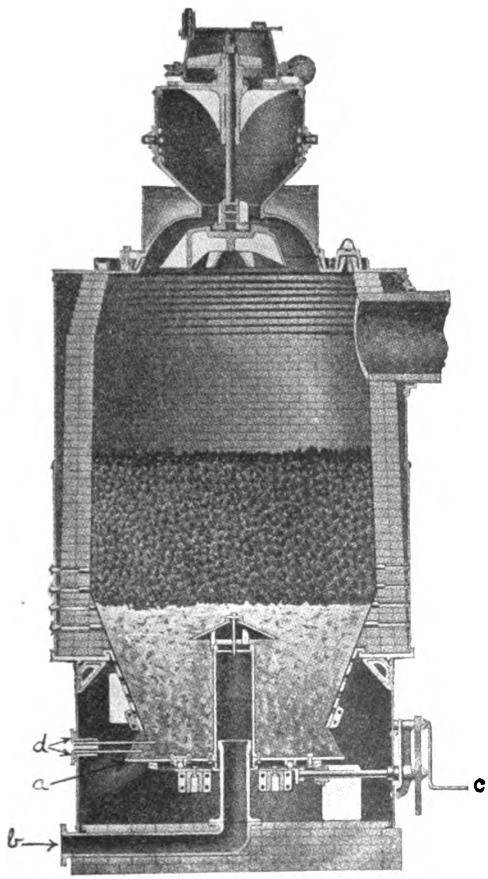


Fig. 45. Taylor Gas Producer.

The scrapers *d*, projecting a short distance into the ash bed, help the discharge of ash from the grate. The depth of the bed of ashes ensures that the ash is completely burned and cooled before it is finally discharged.

Producer Plants are of two kinds, according as the flow of air through the producer is caused by air being forced in from below or by a partial vacuum being created above the fuel. The former is called a *pressure plant*, the latter a *suction plant*.

The general arrangement of the *pressure type* of producer gas plant is shown in Fig. 46, in which the arrows indicate the direction of flow of the gas. A small boiler supplies steam to the blower. The gas escapes from the producer at a high temperature and goes to an economizer, where it gives up much of its heat either to fresh air, which is about to be forced through the producer, or else to water, the vapor from which mixes with the air. The gas then passes to the scrubber, where it meets a spray of cold

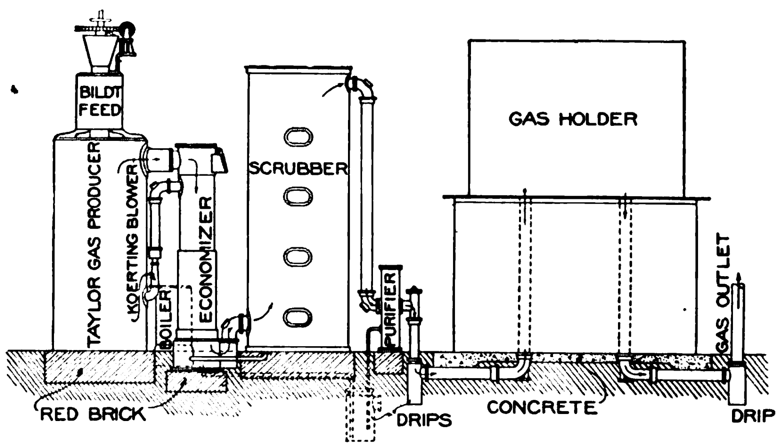


Fig. 46. Producer Plant—Pressure Type.

water, which further cools it and takes from it dust and solid impurity, after which it goes to the purifier for the extraction by chemical process of certain undesirable components and for the completion of the removal of solids, and thence to the gas holder. If anthracite coal or coke are used, very little chemical purification is necessary; if bituminous coal is being burned, the cleaning is somewhat more complicated, as the tar and other troublesome substances in the gas have to be extracted before it can be used.

The *suction type* of gas producer plant can be used only when the operation of the engine is continuous for long periods. It has considerable advantage over the pressure type in compactness, but

is rather troublesome to start. The flow of air and vapor through the fuel in the producer or generator (Fig. 47) is dependent on the sucking action of the engine each time it takes in a charge, so that no boiler is needed to produce the blast. The volume of gas generated is always equal to the amount that the engine uses, so that no gas holder is required between the producer and the engine, its place being taken by a small gas tank. To start the producer working, a small hand or belt-driven blower is used, and the products of combustion are sent past a by-pass valve directly to the atmosphere until the escaping gas will burn steadily. The by-pass valve is then closed, and the gas is forced through the scrubber

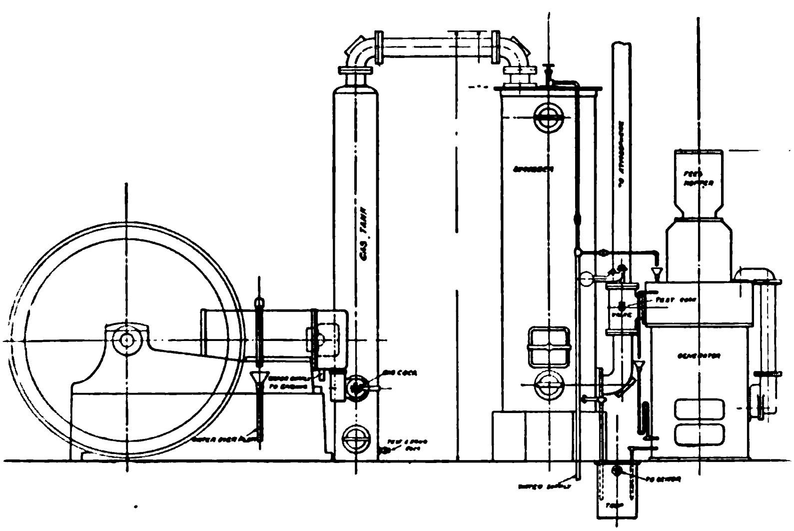


Fig. 47. Producer Plant—Suction Type.

and purifier into the gas tank and the whole apparatus is filled with gas. When good gas appears at a test cock near the engine, the engine is put in operation and the blower is stopped, its function being performed thereafter by the engine. The hot gases escaping from the generator go first through an economizer or vaporizer (not shown in Fig. 47), and the steam formed there is conducted to the under side of the grate of the producer and is sucked through with the air.

Owing to the resistance offered by the fuel, scrubber, and other parts of the plant to the passage of the gas, its pressure on

reaching the engine is considerably below the atmospheric pressure. This causes a decrease in the weight of the charge taken to the engine, and so makes the power of the engine less than when pressure gas is used. In order to get the high compression which is necessary to ensure ignition with a weak gas supplied at a low pressure, the clearance in the engine using suction gas is smaller than in other engines using the same cycle. It is not safe to use such an engine with illuminating gas, as the pressures resulting from explosion would be excessive. When in some cases illuminating gas is used to start the engine, a special device is used to exhaust some of the charge during the compression period, and so to reduce the compression pressure.

An efficient producer of either the pressure or suction type will waste not more than fifteen to twenty per cent. of the heat of combustion of the coal in converting it into gas—that is, the gas on burning will give up eighty to eighty-five per cent. of the heat of combustion of the coal. Its efficiency exceeds that of a steam boiler. If the gas produced is a weak one, it is produced in greater volume, and it has to be mixed with a much smaller volume of air than is required for illuminating gas. For example, ordinary coal gas must have at least six parts of air to one of gas, whereas producer gas requires a minimum of about one-and-a-quarter parts of air to one of gas.

The heat liberated by the combustion of a cubic foot of each of the gases discussed is as follows:

Natural gas	900 – 1000	B.T.U.
Coal gas	650 – 700	"
Water gas	300	"
Producer gas	120 – 150	"

The power which can be developed in an engine does not depend upon the heat of combustion of a cubic foot of the fuel but on the heat of combustion of a cubic foot of the explosive mixture. The difference in the amounts of air necessary for combustion with the different gases makes the heats of combustion per cubic foot of the explosive mixture much more nearly equal than the heats of combustion per cubic foot of the fuel. Thus, when mixed with just sufficient air for complete combustion, nat-

ural gas, coal gas, and water gas will all give up about 90 B.T.U. per cu. ft. of the explosive mixture, while producer gas gives up about 65 B.T.U. An engine will consequently develop about the same power whether using natural gas, coal gas or water gas; with producer gas it will develop considerably less power.

Blast Furnace Gas. Besides the gases produced from solid fuels for illuminating or power purposes, there are waste gases escaping in many industrial processes (notably in the production of pig iron) which have considerable heat value. These gases have been utilized by burning them under a boiler for the generation of steam, but they are generally satisfactory, after cleansing, as fuels for a gas engine, and when so used give three or four times more power than when used for steam generation. The gases escaping from a blast furnace have a heat value of about 100 B.T.U. per cubic foot. Even when the gas is so poor that it will not burn under a boiler, it can be made to burn satisfactorily in a gas engine because of the high compression to which it is subjected.

The Care of a Gas Engine. For the successful operation of a gas engine intelligent care and accurate adjustment are necessary, and also an understanding of the processes going on in the cylinder. It sometimes happens that the engine fails to start, although the ordinary starting operations have been carried out faithfully. The most common causes of this difficulty are incorrect strength of mixture, failure of ignition and leakage of the charge. The setting of the gas valve which gives a satisfactory mixture one day may give a non-explosive mixture on the following day as a result of variation of pressure of the gas or other change. The strength of the mixture should be varied in case of failure to start. If this is ineffective, the ignition should be tried. The batteries may have run down as a result of much use or of short circuiting, and should be tested by short circuiting momentarily, when they should give a bright spark. Too strong a current is undesirable, as it burns the contact points rapidly. It is well to have on hand a spare set of cells for putting in circuit. There should always be a switch in the battery circuit, which should be thrown out when the engine is shut down, so as to prevent short circuiting. If the battery is in good condition, the

trouble may be with the electrodes, either by their having become fouled or wet, or, in the make-and-break system, by a gumming of the spindle of the moving electrode which makes it sticky and slow in action. The igniter plug should be withdrawn and the electrodes examined. The whole igniter circuit should be examined for short circuits.

If the trouble is not with the igniter it may be caused by leakage of the charge. To test this, the engine, if not too large, is pulled over by hand. The resistance to turning on the compression stroke should be very considerable. If the resistance is not very great, or decreases, the compressed charge is escaping. The leakage may be either past the piston, the igniter plug or the valves. If the leakage is past the piston, it is either due to the wearing of the cylinder or to the sticking of the piston rings. The latter is very liable to occur after a while, especially if the cylinder has been permitted to get very hot, and can be remedied by taking the piston out and loosening and cleaning the rings with kerosene. A leakage past the valves is due either to gumming of the valves or to other deposit which keeps the valve off its seat, to wearing of the valve, or to sticking of the valve stem in its guide as a result of imperfect lubrication. The gumming and wear of the exhaust valve is the most common of the causes of leakage and may be remedied by grinding the valve on its seat with flour of emery and oil.

The presence of water in the cylinder, which has leaked in from the jacket through imperfect joints, sometimes causes the electrodes to become wet and prevents the engine starting. In some engines the possibility of this particular trouble is avoided by a special design of the jacket which has no joints communicating with the inside of the cylinder.

The cylinder oil that is used in steam engines cannot be used in gas engines, as it carbonizes at the high temperature of the explosion, and forms a deposit in the cylinder and on the exhaust valve. A much lighter oil is used, and even this if supplied in excess causes a gradual accumulation of hard deposit in the cylinder which must be cleared out occasionally. Apart from its interference with the action of the igniter and exhaust valve, it is liable to cause premature ignition by being raised to incandescence.

Cold water must be kept circulating through the jackets whenever the engine is running, being started as soon as the cylinder warms up. A stoppage of this flow, even for a comparatively short time, is liable to have a disastrous effect upon the cylinder. A gradual accumulation of sediment may occur in the water jacket, with a consequent reduction in its efficiency. On shutting down, it is always better to drain the jacket, which not only prevents the possibility of its freezing up in winter, but also tends to clear it of deposit of sediment. Generally, however. the jackets are drained only in cold weather.

In the running of a gas engine—especially under light loads—very loud and alarming explosions are sometimes heard in the admission pipe or in the exhaust pipe. The *back firing* in the admission pipe nearly always results from a leaky admission valve. The explosions in the exhaust, indicating as they do the presence of explosive gases in the exhaust pipe, are caused either by the use of a mixture which is too weak or by faulty ignition. If the mixture is too weak, the charge taken in just after an explosion may fail to ignite because it is mixed with the products of the previous explosion, while the next charge taken in may explode because it does not mix with burned gas but with the weak charge in the clearance. The hot exhaust gases ignite the weak mixture which was rejected unburned to the exhaust at the previous cycle. If the ignition is imperfect, a good mixture may fail to explode and be exhausted, and then ignited in the exhaust pipe by the next exhaust of hot gases.

Large Gas Engines. A very rapid development has taken place in the size to which gas engines are built until they are now made as powerful as the largest steam engines. To obtain large powers and to get the desired uniformity of crank shaft movement, multi-cylinders and multi-cranks are commonly used. When double-acting cylinders are used, the piston being subjected to high temperatures on both sides, becomes too hot unless there is a circulation of cooling water within it. If the piston is to be water-cooled, the piston rod is made hollow and is furnished with an internal tube. A water pipe is attached to the piston rod near the crosshead, by means of swing joints, and a current of water flows through the internal tube to the piston, circulates through it

in a regular path, returns along the annular space around the internal tube in the hollow rod and escapes through other pipes with swing joints.

To obtain an impulse each stroke from a single cylinder engine (Fig. 48) a two-cycle double-action engine may be used. In this engine the exhaust occurs by the uncovering of the ports in the middle of the cylinder when the engine is near the end of its stroke. The air and gas that are to be admitted are compressed separately in the cylinders B and A respectively. When in consequence of the opening of the exhaust, the pressure in the cylinder falls below that to which the air is compressed, air enters

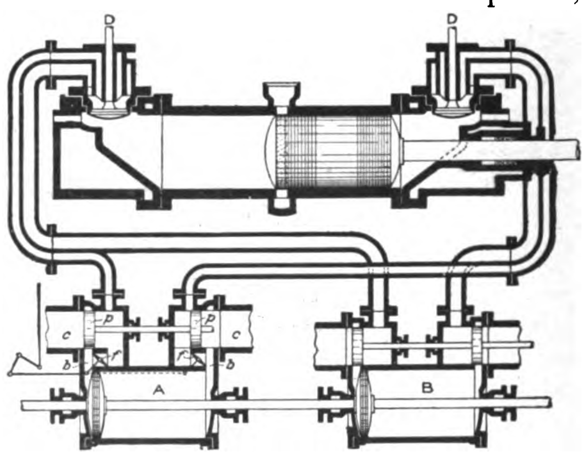
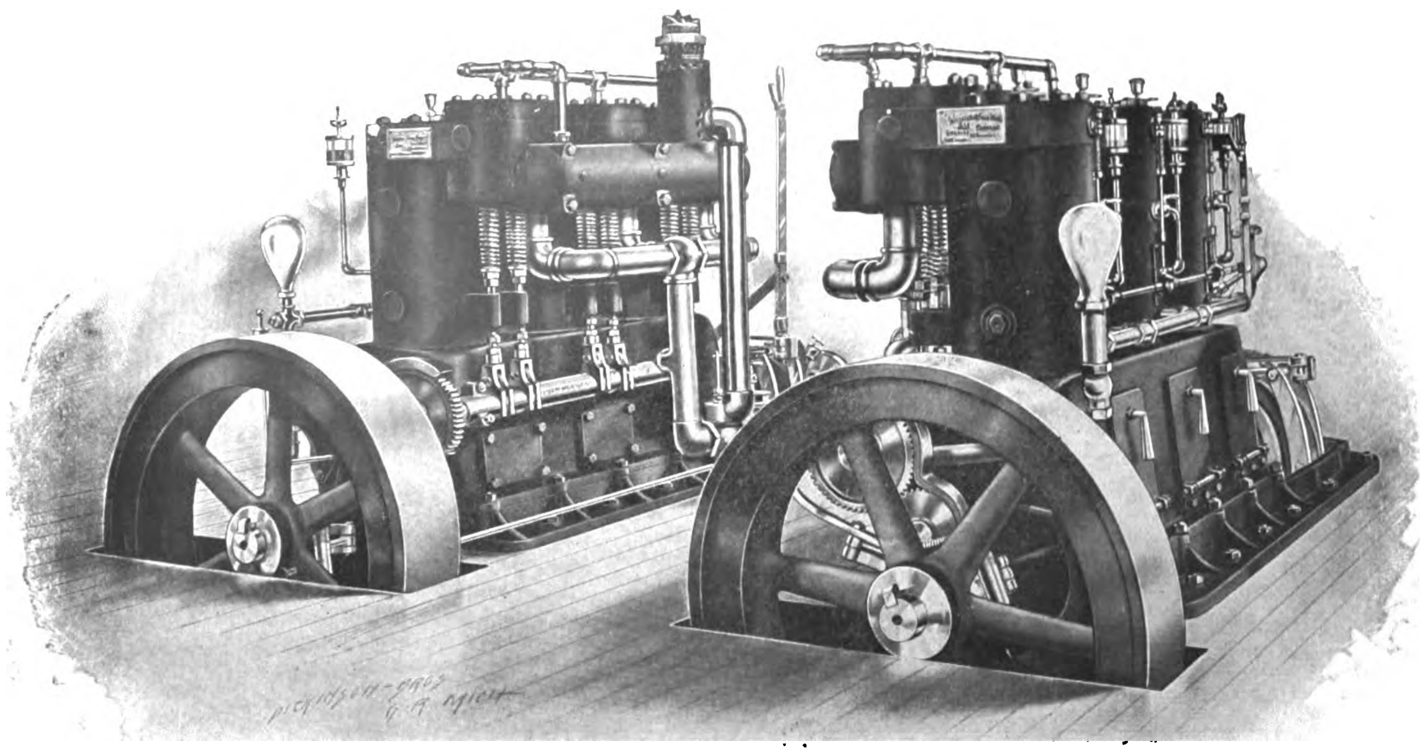


Fig. 48. Koerting Gas Engine.

through the automatic valve D at the top of the cylinder, and rushing toward the exhaust port, sweeps the cylinder clear of burned gas. The gas admission valve opens immediately afterwards, and an explosive charge enters; but before this can get to the exhaust port, the return of the piston stops the exhaust. In this way the cylinder is kept clear of burned gases without the loss of any of the entering charge. The propagation of the explosion in the cylinders of large engines is comparatively slow, so that two or more igniters are sometimes used so as to start the explosion in several places simultaneously.

Fuel Consumption. The consumption of fuel in a gas engine running at its rated load when natural gas is used, is from 13 to



FORWARD VIEW OF A PAIR OF 27 H.P 3 CYLINDER 4 CYCLE BALANCED TWIN SCREW GAS ENGINES.

Wolverine Motor Works.

17 cu. ft. per B.H.P. per hour; with coal gas 15 to 19 cu. ft. per B.H.P. per hour, and with producer gas about $1\frac{1}{4}$ lb. of coal per B.H.P. per hour. These are average good results; large engines show higher economy than smaller engines and have given a B.H.P. with a consumption of 1 lb. of coal per hour.

Oil Engines. The fuel used in oil engines is generally *crude petroleum* or some of the oils derived from it by the process of refining. Crude petroleum is not a simple chemical substance, but is a mixture of a very large number of different hydrocarbons having widely varying properties. If crude petroleum is slowly heated, it gives off as vapor its various constituent elements, the more volatile being given off at the lower temperatures, and the residue becoming continuously more dense and more viscous. In the refining of petroleum the vapors given off at various temperatures are condensed and collected separately, and the names given to the various products are an index chiefly to the temperature at which they give off their vapors. The most volatile of the ordinary products contains all the elements that vaporize at a temperature below 160° F., and is called *gasoline*. It gives off some of its lighter vapors at the ordinary temperature of the air, and as these vapors are highly combustible, gasoline is quite dangerous. When mixed with from eight to twenty parts of air, it forms an explosive mixture, which gives a more rapid explosion and consequently higher pressure than mixtures of equal heat value used in the gas engine. When exposed to the air, the lighter vapors escape, leaving behind a heavier and less volatile oil.

If petroleum which has been heated for some time at 160° is slowly raised in temperature to 250° F., a new and heavier series of vapors will be given off, which, when condensed and collected, are called *benzine* or *naphtha*. On still further raising the temperature from 250° F. to 350° F., a still heavier series of vapors is given off, forming the oil known as *kerosene*. Kerosene will not give off inflammable vapors till it is heated to about 120° F., so that it is comparatively safe and also will not change or deteriorate when stored under ordinary conditions. It is more difficult to burn satisfactorily than is gasoline, and when subjected to a high temperature with insufficient air for its combustion, it decomposes and deposits its carbon as a hard cake on the walls of the contain-

ing vessel. The dense petroleum which remains after the kerosene has been driven off is called *fuel oil*. If the fuel oil is subjected to still higher temperatures other and denser vapors are driven off, giving when collected *lubricating oils*, *cylinder oil* and *paraffine wax*, leaving finally a dense sticky mass which is known as *residuum*. The various oils can be distinguished in a general way by their densities, that is, their weights as compared with the weight of an equal volume of water. The density of gasoline is about .65, of kerosene about .80, of fuel oil about .82, of lubricating oils up to .92. If it is stated that an engine uses .76 kerosene, it means that the density of the kerosene is $\frac{76}{100}$ of that of water.

Crude petroleum, gasoline, kerosene and fuel oil are all used in oil engines. The cycle of operations through which the engine goes and the general structure of the engine may be the same for all these oils as for the gas engines already discussed; the only essential difference is in the addition of devices for supplying the oil to the cylinder and for its preparatory treatment.

Oil engines may be divided into two classes:

1. Those that convert the oil into a fine spray or a vapor before admitting it to the cylinder.

2. Those that deliver the oil to the cylinder in the liquid form.

Gasoline Engines. When gasoline is used, the vaporization is brought about by passing a current of air over or through the oil; the air escapes enriched with vapor of gasoline, and is said to be *carbureted*. The vessel in which the process takes place is called a *carburetor*. The carbureted air is too rich in fuel to be explosive, so that a further addition of air is necessary at the cylinder. The vaporization of part of the oil results in a lowering of temperature of the main body of the oil, and this reduces its volatility. In order to carry out the process satisfactorily with a uniform quality of the carbureted air, it is customary to heat the carburetor. This may be effected by making use of the heat either of the exhaust gases or of the escaping jacket water. The latter is more common with gasoline. A further advantage of moderate heating of the carburetor is that the denser constituents of the gasoline then become more volatile, so that the passage of the air through the oil does not result in depriving it of its lighter constituents and in leaving a residue too dense to be used.

The carburetor shown in Fig. 49 consists of a vertical cylinder surrounded by a water jacket. Gasoline is pumped to the top of the cylinder and, passing through a spraying device, falls in a finely divided state. It meets an upward current of air drawn in through inlets at the bottom by the suction of the engine cylinder. The carbureted air goes from the top of the carburetor to the engine, while any unvaporized gasoline drains to the suction side of the gasoline pump and is returned later to the carburetor. The water jacket has circulating through it some of the heated jacket water from the cylinder. The actual temperature of the jacket is controlled by a thermostat which varies the amount of water circulating.

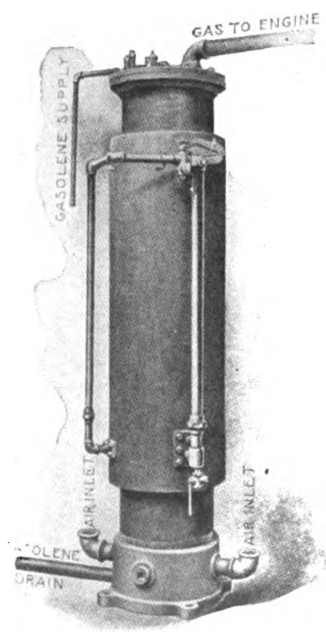


Fig. 49. Westinghouse Carburetor.

Gasoline is very fluid and atomizes completely when injected into a pipe through which a current of air is passing. The air in that case carries the gasoline with it, partly in the form of a mist and partly vaporized. This process is largely used in gasoline engines, and is illustrated in Fig. 50, which shows the whole arrangement of a gasoline plant. The gasoline tank is buried below the floor level and outside the building, so as to reduce the danger in case of fire or explosion, and also so that there can be no leakage of gasoline from the pipes when the engine is not running. The gasoline is taken through a strainer near the bottom of the tank and through the suction pipe by the action of a gasoline pump, which is worked from the cam shaft. It is then forced through the control valve A and is sprayed into the air pipe N through the jet H whenever the fuel admission valve G opens. A vertical branch of the discharge pipe from the gasoline pump has an overflow connecting with the tank. The pump always delivers more gasoline than is required, the excess being returned to the tank through the

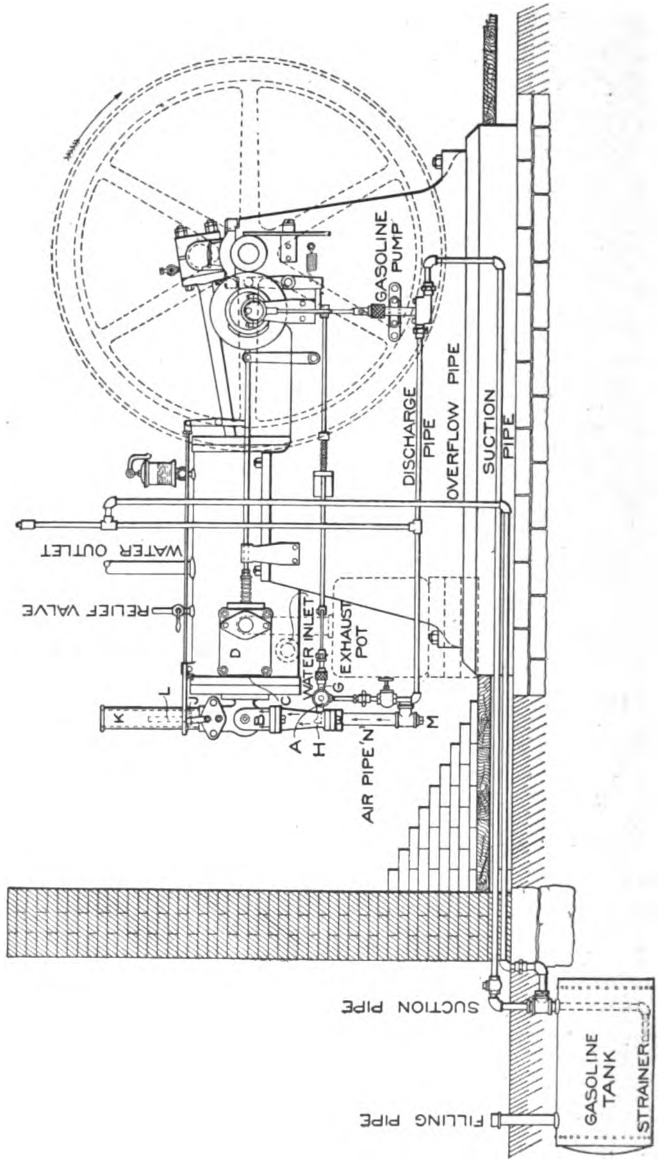


Fig. 50. Charter Gasoline Engine.

overflow pipe. This maintains a constant pressure of the gasoline depending only on the constant overflow level. With a given opening of the control valve A and a constant head on the gasoline, the amount of gasoline admitted each time remains constant.

An engine using gasoline is usually provided with a clearance space somewhat larger than that used in a gas engine, so as to prevent excessive pressures during explosion. The indicator card, Fig. 51, shows the rapidity and force of the explosion in a gasoline engine.

Kerosene and Crude Oil Engines. When kerosene or heavier oils are to be burned, different methods from those described for gasoline must be used. The kerosene is generally broken up in the carburetor into a fine spray or mist by a current of air; it is then sent to a vaporizer before being admitted to the cylinder. In the vaporizer the carbureted air is raised to a high temperature, the heat of the exhaust gases being utilized for this purpose, and the kerosene is converted into a vapor. Unless the kerosene is completely vaporized before admission to the cylinder, it is difficult to ensure its complete combustion. Some of the liquid kerosene in the cylinder *cracks* or breaks up into its elements as a result of the very high temperature to which it is subjected, and the carbon deposits itself on the piston and walls of the clearance space as a hard coating. The temperature in the vaporizer is not sufficient to crack the oil.

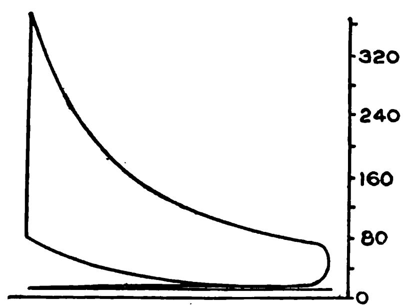


Fig. 51. Indicator Card of Gasoline Engine.

In some cases the carburetor or spraying device is omitted and the oil is pumped directly into a vaporizer or generator which converts the liquid into a vapor. A device of this kind for burning heavy crude oil, such as is found in the Texas oil fields, is shown in Fig. 52. The generator G is placed close to the engine so that the hot exhaust gases coming through the pipe N shall not be cooled before reaching it. The oil pumped by the engine goes through the pipe F to the small reservoir R on top of the gener-

ator, any excess returning by the overflow pipe O to the main supply tank. The amount of oil entering the generator is controlled by the throttle valve T at the reservoir R. The oil trickles down over surfaces which are heated by the exhaust gases and is partly or completely vaporized. Any unconsumed residue drains off through the cock D at the bottom of the generator. The temperature in the generator is regulated by a heat valve E, which may be set so as to circulate all or any part of the exhaust gases

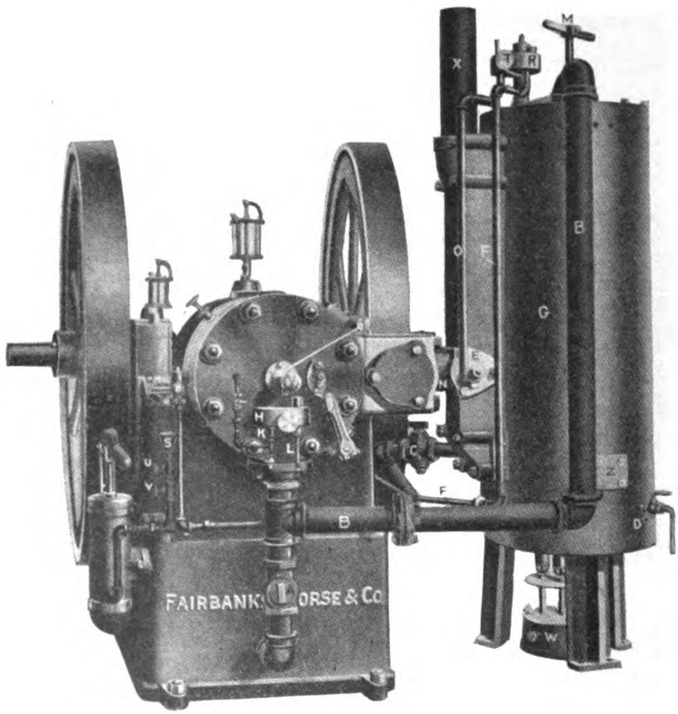


Fig. 52. Fairbanks-Morse Engine Arranged for Burning Heavy Crude Oil.

through the heating coil of the generator, the rest being sent directly to the exhaust pipe X. Air is drawn into the lower part of the generator through the pipe C, and the mixture of air and vapor leaving the top of the generator by the pipe B, meets a fresh supply of air arriving through the valve A before being admitted to the cylinder. When kerosene is to be used, the generator is very much smaller, but the general arrangement is similar

Kerosene and the heavier oils can be used in oil engines without preliminary vaporization. One of the methods of accomplishing this is illustrated in Fig. 53, which is a longitudinal section of an engine using kerosene or crude oil. A combustion chamber or vaporizer A is attached to the end of the cylinder and communicates with it through a narrow neck B. The outer part of the vaporizer is unjacketed, and consequently is kept at a good red heat by the successive explosions. The engine follows the usual four stroke cycle. During the admission stroke air alone is admitted to the cylinder, while oil is injected into the combustion chamber and is vaporized there. During the return stroke the air is

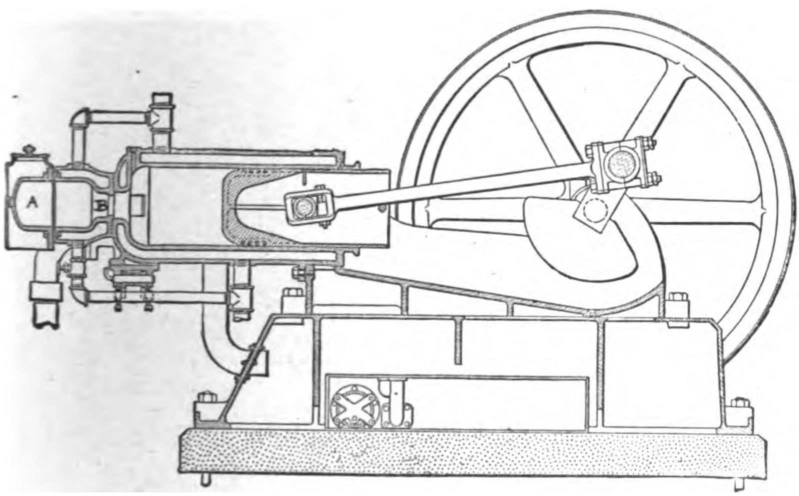


Fig. 53. Hornsby-Akroyd Oil Engine.

compressed into the vaporizer, mixes with the oil vapor and forms an explosive mixture which is ignited by the hot walls of the combustion chamber. The proportions of the combustion chamber are designed so that the explosion does not occur till near the end of the compression stroke. The fuel supply is regulated by the governor, which controls a by-pass permitting part of the discharge from the pump to return to the suction side. Before starting the engine the combustion chamber must be raised to a bright red heat by an external heater; but after starting, it is maintained in that condition by the explosions. The engine is of great simplicity since it dispenses with both igniter and mixing valve. The com-

bustion chamber becomes coated with a deposit of carbon resulting from the cracking of the oil at the high temperature, but it is easily removed for cleaning.

The Diesel Cycle. All the engines discussed so far have operated on the Otto cycle or some modification of that cycle. There is coming into use for crude oil or fuel oil engines another cycle of operations, known as the Diesel cycle, which merits attention because of its high efficiency. The cycle will operate equally well with gas or gasoline, but is naturally used with the cheaper fuels. The Diesel cycle resembles the Otto cycle in requiring four strokes for its completion. The first out stroke draws into the cylinder a charge of pure air alone, without any admixture of the fuel. On the return stroke the air is compressed; and since the clearance in this engine is only about seven per cent of the cylinder volume, the pressure at the end of compression rises to about 500 lb. per sq. in., and the temperature of the air to about 1,000° F. As the high pressure is reached gradually, it does not cause a shock to the engine, such as an explosion to the same pressure would give. At the beginning of the second out-stroke the oil admission valve opens and a charge of oil is blown into the cylinder in the form of a fine spray by a small quantity of air which has been compressed by a special compressor to about 550 lb. The moment the entering oil meets the highly heated air in the clearance space, it ignites and burns. The combustion goes on so long as the fuel is being blown in, usually for about one-tenth of the forward stroke; and since there is no large quantity burning at any instant, there is nothing in the nature of an explosion. Usually the heat generated by the combustion is not sufficient to prevent the pressure in the cylinder falling while the admission is taking place, so that the admission line on the indicator card falls below the constant pressure line as seen in the indicator card, Fig. 54. The method of burning is really essentially similar to that of an ordinary gas burner, and not to that of an explosive mixture, and consequently the oil will burn with any

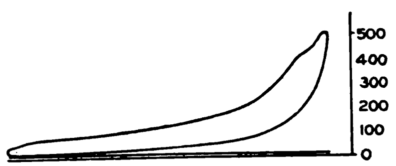


Fig. 54. Indicator Card—Diesel Engine.

excess of air present. After the admission valve has closed, the charge expands and then is exhausted on the return stroke. The indicator card, Fig. 54, shows the cycle of operations.

The general structure of the engine and a detail of the valves are shown in Figs. 55 and 56. The movement of the fuel admis-

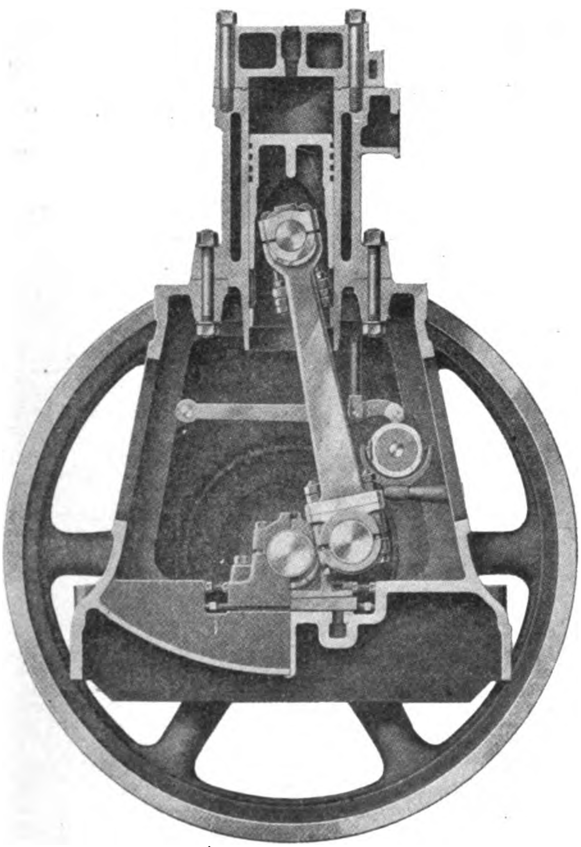


Fig. 55. Sectional View—Diesel Engine.

sion valve is very slight, giving a narrow annular opening for the entry of the oil. Surrounding the valve spindle is a series of brass washers perforated parallel to the spindle by numerous small holes. The oil is pumped into the space around the valve spindle near its middle, and by capillary action finds its way between the washers and into the perforations. The air for fuel injection is

admitted through another pipe into the same space, but behind the oil, and because of its high pressure blows the oil into the cylinder when the valve opens. The amount of oil admitted is regulated by the governor which controls the time of opening of a by-pass connecting the discharge and suction sides of the oil pump. At light loads the oil is pumped to the fuel valve for part only of the admission period, and air alone will enter past the valve for the rest of the period. The method of slow combus-

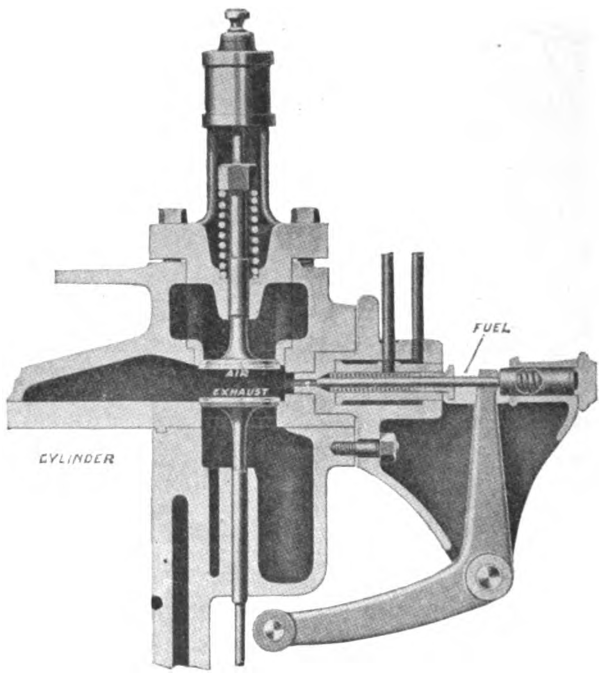


Fig. 56. Valves of Diesel Engine.

tion in a large excess of highly heated air ensures very complete combustion even with the heaviest oils, so that there is no chance for the accumulation of a carbon deposit in the cylinder. The engine is started by compressed air from an auxiliary reservoir, a special starting valve being used for the purpose. Diesel engines have, under test, converted more than 35 per cent of the heat of combustion of the oil into work done in the cylinder.

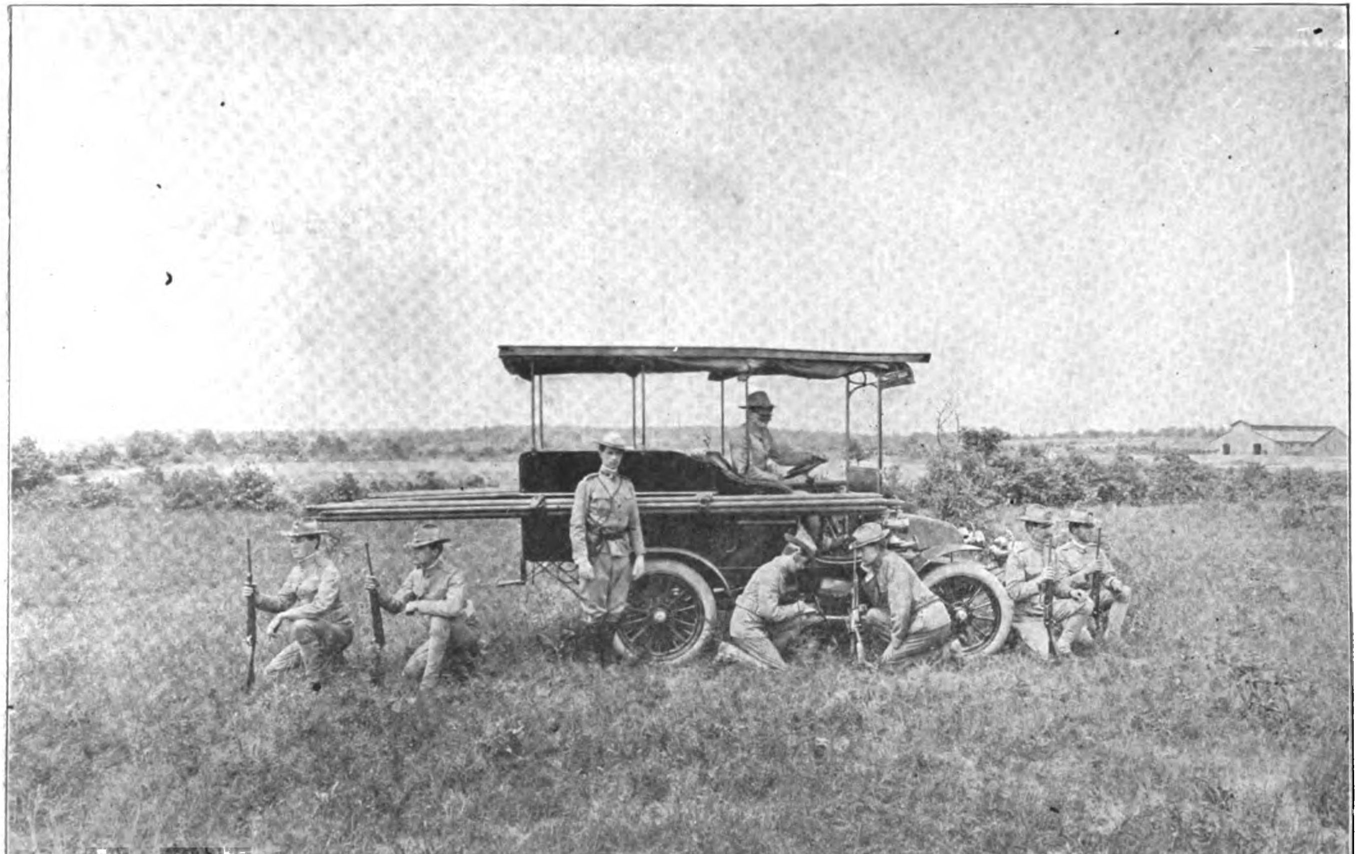
The Care of the Oil Engine. The same general precautions are necessary in running an oil engine as in running a gas engine,

and the same troubles are liable to occur. The starting by hand of a gasoline engine of small size has been described already. If the engine fails to start, it will probably be because either too much or too little gasoline was admitted. The amount admitted for starting must be varied with the temperature of the cylinder. In cold weather about twice the normal amount must be used, while on the other hand, if the engine has been running and has been shut down for a short time only, a considerable diminished charge is necessary.

Great care must be taken by the use of suitable strainers that no solid foreign matter gets into the oil supply pipe, otherwise there is great liability to the obstruction of the flow. Owing to its more rapid explosion and to the greater richness of the explosive charge, a gasoline engine will develop more power than a gas engine of the same size, even when the latter uses natural gas.

Oil Consumption. The consumption of gasoline in an engine of small size averages about one-tenth of a gallon per brake horse power per hour. In the Diesel motor the average consumption of crude oil per brake horse power per hour is less than one-tenth of a gallon.

The field for the use of the oil engine is very extended. It is the most compact of the heat engines, requiring nothing equivalent to boiler or gas generator, and consequently is inherently the most suitable for purposes of transportation. Its extensive adoption for driving automobiles and motor boats is being followed by its application to locomotives and to large vessels. The absence of boiler and of heat generator losses makes it both potentially and actually the most efficient of all heat engines. The relative cost of power developed by oil, gas and steam engines depends on the cost of the oil and of coal, and this varies with the locality and the kind of oil or coal. In refining petroleum not more than ten per cent of the oil can be collected as gasoline, so that this oil, which is the most easy to use, is not available in as large quantity, and consequently has a considerable higher cost than the heavier oils. Kerosene forms twenty-five to fifty per cent of the crude oil, and is consequently cheaper. Fuel oil and crude oil are the cheapest, but are also the most difficult to burn satisfactorily.



USE OF THE AUTOMOBILE IN WAR.—AUTO-TELEGRAPH CAR OF THE SIGNAL CORPS, U. S. ARMY.

A Scene during the Manœuvers of 1904 on the Historic Battlefield of Bull Run.

AUTOMOBILES

As a device for saving time and distance, the motor vehicle bids fair to eclipse all others and to prove itself one of the greatest inventions of an inventive age. Its motor will, in time, be built cheaper than a horse can be grown, its transmission gear will cost less than a harness, while its body need cost little, if any more than similar parts of horse vehicles. Rapid as has been the growth, and astonishing as are the re ults shown to-day by this class of vehicles, it is evident that this is but the beginning and that in the very near future, a development and growth far beyond present conception is sure to come.

The motor vehicle is not a new invention. It is the father of the traction engine and of the locomotive. It is one of the devices earliest sought for but latest to be practically and popularly worked out; and few problems of greater severity have been presented to engineers. Its need has Leen felt everywhere, for we spend our lives exchanging what we have for what we desire and this requires transportation. At both ends and often between ends of the route over which the exchange is made animal power is used and here the auto is needed and will be used with great saving. The director of the United States Road Inquiry Bureau says the cost of moving tonnage 1250 miles by steamships, 250 miles by steam cars, or 25 miles by electric cars is no greater than the cost of moving tonnage 5 miles by animal power on the common roads—a proportion of 1 to 5, 1 to 50 and 1 to 250 in favor of mechanical transportation against the horse; and yet with these figures before them, capitalists build larger steamships and better railways in an attempt to save an additional slight percentage on these already cheap methods, while the horse has continued to draw the same old wagon at a snail's pace over abominable roads, simply because heretofore the motor vehicle has not come into use.

On the other hand while this has been the general condition, there have always been attempts to secure better results. Pioneers have exerted themselves to build mechanical motors for use on the common

1

roads in the face of the great chances of failure and the derision of the world. To them we owe the progress that has been made.

HISTORY

Nearly three centuries ago a German at Nuremberg proposed to drive vehicles "2000 paces an hour by means of springs," and similar carriages were proposed by others. In 1759 Dr. Robinson called the attention of Watt to the possibilities of steam vehicles. In 1763 to 1769 Cugnot, a Frenchman, designed and built with the assistance of the French War Department, a steam-propelled gun-carriage and in 1797 a four-passenger tricycle capable of four miles per hour. In England a practical result was shown in 1781 by Murdock and in America by Oliver Evans in 1804. These were mostly steam vehicles, although gunpowder engines much resembling gas engines were among the earliest proposed. Compressed air was also used, notably by Mann in 1822 and others.

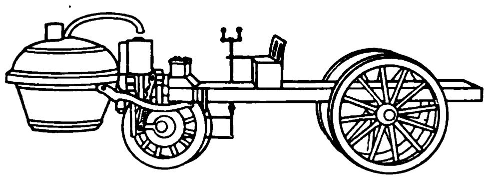


Fig. 1. Cugnot's Steam Carriage, 1769.

The first half of the 19th century was marked by many attempts at motor road-locomotion and many vehicles, particularly omnibuses for public hire, were made and operated between 1820 and 1844 by Hancock, Gurney, Church, Fisher, James, Squire, Russell (constructor of the Great Eastern Steamship) and others. These vehicles were operated with success on regular schedules over regular routes, were much liked by travelers and were crowded with passengers, and they bade fair to inaugurate the horseless age and bring in an era of cheap transportation.

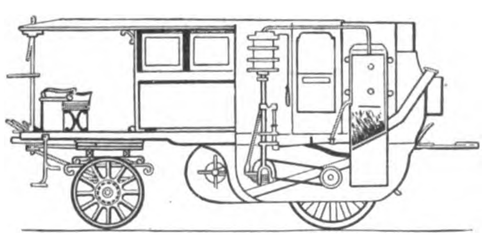


Fig. 2. Hancock's Steam Carriage, 1835.

Public opinion, however, was not with these vehicles. Horse users and stage drivers were very bitter against them. The Road

Trustees imposed unjust and discriminating tolls and the ill feeling and prejudice finally resulted in restrictive laws prohibiting a speed faster than three or four miles per hour and compelling a man to precede the vehicle with a red flag. The result was that the industry died and did not again exist in England until the passage of the "Light Locomotives Act" in 1896, a loss of more than 50 years and of millions of dollars that would otherwise have gone to the English nation. In the meantime the locomotive was developed to run on special rights of way and the traction engine plodded at a snail's pace whenever it used the highways.

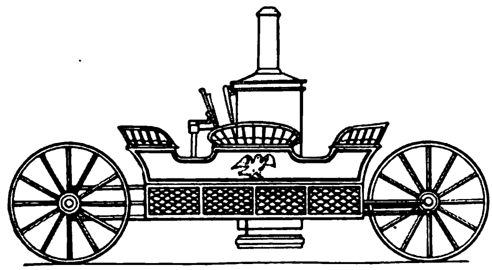


Fig. 3. Fisher's Steam Carriage, 1840.

Occasional Experiments. Occasional inventors made experiments from time to time in France, Germany and America, but for one reason or another none of these found favor In 1860 to '62 Lenoir, a Frenchman, designed a gas engine of the four stroke cycle type and applied it to a motor vehicle. Ten years later the elder Bollee built one or more steam vehicles which received some use on French roads. About 1876 Fawcett, at Pittsburg, built an omnibus using a Brayton internally fired engine burning liquid fuel. Ten years later Copeland in America fitted small, light steam motors to bicycles and tricycles with some degree of success, while Daimler and Benz in Germany about the same time applied gas engines of the four cycle type successfully to motor vehicles.

The next ten years marks the beginning of the present motor vehicle industry. In Germany, Daimler developed the small high speed motor which is admittedly the predecessor of present day practice. Benz, his countryman, confined himself more to the application of engines resembling stationary engines, and while very successful, so far as quantity of vehicles made and service rendered is considered, did not influence the industry as did Daimler whose inventions were taken up in France about 1892 or '93. In America, occasionally experimenting since 1886, the Duryea Bros. began continuous work

on gasolene vehicles in 1891, which work unlike many experiments, has been carried forth continually since. In 1893 Sturgess, of Chicago, exhibited an electric vehicle at the Columbian Exposition.

In 1894 and 1895 very successful road contests were held in France and attracted the attention of the civilized world. These were followed by several automobile events in America, the first of which was the Times-Herald contest at Chicago.

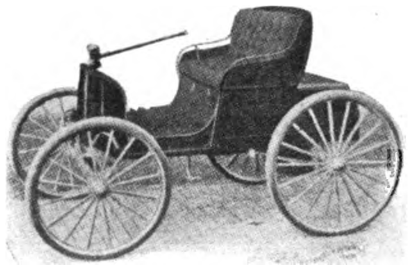


Fig. 4. Five Horse-Power Runabout, 1896 Model.

Pioneers. It is difficult in a historical account, to set a proper value on the various experiments and attempts made in different parts of the world, for no one can say what bearing or influence any particular experiment may have had on the work of later builders. It is eminently proper, however, to give credit to work that has continued with little or no interruption into the present period; to work that showed marked pre-eminence either by the results accomplished or by the means and mechanism used, and to work that has in any way stamped itself upon present practice to a noticeable extent. Judged by these standards the pioneers in the electric vehicle field were Sturgess, 1893, Morris & Salom, 1894 and '95, Woods, 1895 and Riker, 1896. In steam vehicles the work of Copeland (given considerable prominence through the Cycle publications), was followed about 1896 and '97 by the successful steam carriage of Whitney, which was the direct predecessor of the product of the Stanley Bros., first introduced to the public at Charles River park, Boston, Mass., in the fall of 1898. In gasolene vehicles, the

Fig. 5. Two and One-Half Horse-Power Phaeton, 1902 Model.

APPERSON 100 HORSE-POWER RUNABOUT, PRICE $11,500
The most expensive automobile of domestic manufacture shown at the Chicago Automobile Show, 1906

first Duryea finished in 1892, and the second one finished in 1893, both of the single cylinder variety, were followed in 1894 by the double cylinder carriage which won the Chicago Times-Herald contest. The first single cylinder Haynes vehicle was finished in the summer of 1894, followed late in 1895 by the second Haynes, a two cylinder vehicle, the first of the opposed cylinder type. In 1896 the first Winton made its appearance, while in this same year more than a dozen Duryea vehicles were completed and the new industry was fairly started on its way.

Little Interest. Progress was at first slow both in America and England, although more rapid in Germany and France, due to the favorable roads, liberal laws and greater interest among experimenters and capitalists. In America, the downfall of the bicycle business destroyed much of the financial confidence necessary to the development of the new industry and interest lagged until the steam vehicle shown by the Stanleys in 1898, and offered to the public by many makers at a low price, began to be put on the market in a large way and extensively advertised. It met with an enthusiastic reception, was not protected by patents and was therefore largely copied by other makers, with the result that it seemed to have the field to itself. The steam vehicle, as then constructed, however, fell from popularity, even more rapidly than it attained it. The great complexity, the delicacy of the many parts, the small wheels, the inadequate tires, the short wheel base, together with many other features of similar character, all contributed to the downfall of this promising, popular carriage.

In the meantime, the electric vehicle was being exploited by large capitalists in the large cities for public service, and cab companies, overcapitalized, sprang up in many places, doomed to disappointment because of the lack of experience and the fact that their vehicles had not been proved by years of service to be what was needed for their work. This adverse experience did much toward holding back the adoption of the electric vehicle by many to whom it would have been of great value, and hurt the business generally.

Steady Growth. Across the ocean Serpollet, beginning about 1886, had been slowly developing a promising steam vehicle while one or more experimenters were developing the electric. The gasolene vehicle, pushed by many, made most rapid progress. In America also, it made progress conservatively but steadily. Fathered by mechanics,

rather than by capitalists and promoters, it was steadily improved, its defects and limitations were studied, it was sold at a price consistent with good quality, and although slow in coming to its recognition, the certainty of that recognition was made more sure by the very length of the period devoted to its development.

This slow growth gave opportunity for experimentation and brought into existence most of the valuable features of present day autos as well as some features that will undoubtedly be used in future years, although not recognized at their true value now. Thus the first Duryea vehicles, finished in 1892 and 1893, had front axles fitted with wheel pivots or steering heads as close to the wheels as possible, and these pivots were inclined, so as to strike the ground at the bottom at the point of contact of the wheel, which arrangement secures a steering that is practically irreversible, that steers very easily and permits running over obstructions with no shock on the steering parts or tendency to deviate from a straight line—facts which are not yet fully known by constructors and therefore not made use of to a large degree. They employed a three point rear frame with motor and transmission mounted closely together upon it, double side-chain drive with balance gear in the counter shaft, electric ignition, spray carburettor, motor lengthwise the body and many other devices that have since become standard practice.

This period of the history of the gasolene vehicle was not influenced by foreign practice and was more truly American and better suited to the American roads and conditions than many present-day constructions, although at that time the full importance of ample power was not recognized, mechanics were untrained, and many vehicles were incapable and unreliable.

Steam Decadence. About the time of the decadence of the steam vehicle fad, 1901, two vehicles of particular importance began to attract attention,—the Olds and the Knox. The Olds is interesting because of the distinctive shape of the body which resembled a toboggan at its forward end, the shape of the springs, which were fastened at one end to the body and at the other to the axles, and the generally light and simple appearance. This vehicle was put out in large numbers at a moderate price, was quite successfully imitated by many other concerns, and was for a time the representative American type, and recognized as such in many parts of the world. The Knox equally

deserves mention because of its system of air cooling, which was really the only successful form for a considerable period. Many attempts had been made at air cooling, but most of them had been failures for one reason or another; but Knox, by his firm belief in the efficiency of threaded pins screwed into the walls of the cylinder, including the head and valve chambers, demonstrated the practicability of this system, and although standing alone, after others had abandoned air cooling, for all except the smallest sizes, has been followed by a great variety of very efficient air cooling methods.

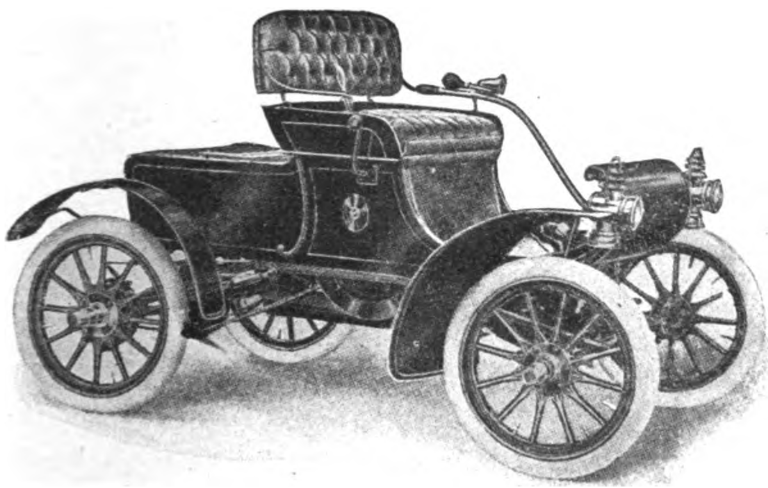


Fig. 6. Standard Oldsmobile Runabout.

Foreign Influence. Abroad, the gasolene vehicle was turned out in large numbers, and was seen, tried, admired, and purchased by the vast number of American tourists, who, too busy at home to even look at an auto, became willing converts abroad and spent their vacations enjoying the good roads of Europe and the new method of locomotion at the same time. The earliest vehicles of Daimler had been fitted with a motor under the seat, but in order to secure greater accessibility he soon transferred this to the front of the vehicle, where it was enclosed in a box, and this practice has prevailed abroad to the present day and has been followed very largely in America through the influence of the tourists.

The splendid foreign roads with their hard surfaces and easy

grades permitted the use of small wheels, of mechanism close to the ground and required so little traction that no great weight was needed upon the driving wheels; while favorable speed laws and road conditions permitted the use of high powers and the attainment of railroad speeds.

American Conditions. In America, where the majority of the roads are bad, the things demanded of a motor vehicle are considerably different, and they are not properly met by foreign designs so prevalent to-day. Rough roads require large wheels, ample clearance under the body, protection of the mechanism from mud and dust, great weight on the propelling wheels, large wheels that will roll over rough places easily, a simple and light mechanism that will stand the rough service with the minimum of repairs. Many other similar features are essential to meet the road conditions and also the needs of a thoroughly practical people, rather than those designed simply to serve as a sport of a leisure class. It seems evident, therefore, that many of the features first developed in America, to meet American conditions, and more or less largely abandoned in favor of foreign design, will eventually become standard American practice, because best suited to American needs. Fluctuations are, of course, apparent in the development of any new industry, for, in their inexperience, the buying public is apt to grasp at new designs as the solution of its difficulties, without really knowing whether the new is better or as good as the old, but as a wider variety of styles is seen in use, these fluctuations will become less pronounced until finally purchasers will have a large variety from which to select and particular needs rather than present fad will more largely influence the selection.

Present Types. Present-day autos can be divided into a wide number of classes in addition to the three general classes, electric, steam and gasolene, already considered. In electric vehicles, there is but little variation except in the shapes of the body, although some vehicles are equipped with two motors, others with but one, and batteries vary somewhat in arrangement, kind, and size, while controllers and fittings exhibit the designers' preferences.

The electric vehicle is of limited range and well adapted to city use for elderly people or ladies. Like the steamer, it seldom needs attention on the road and generally gets home if the batteries are not exhausted. The batteries, like the steam boiler, are the objectionable

feature, for they are quite complicated, heavy, subject to chemical change; also to physical change, such as buckling, loosening of the active matter from the plates and leakage, spilling or evaporation of the electrolyte. The density of the electrolyte needs watching to secure best results, and the batteries should always be kept charged.

Steam Vehicles. These are considered well-known because they employ steam engines and boilers and do not ordinarily use a speed changing device. The White steamer uses a tubular generator in which the water enters the top and is converted into superheated steam by contact with the hot metal. No water is carried in the boiler,

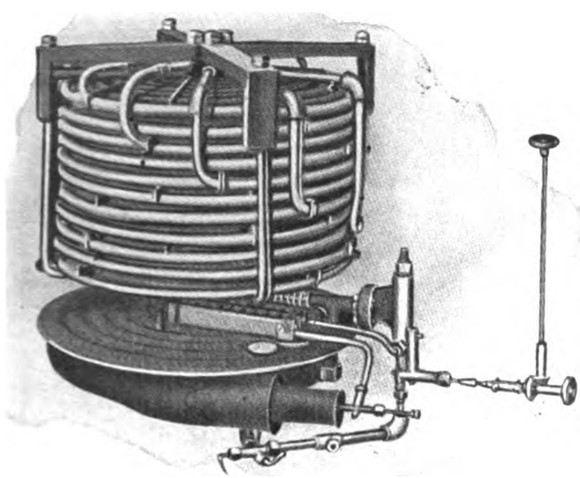


Fig. 7. White Tubular Generator.

so little time is required to get up steam, and an increased supply of water is met by an increased fuel supply, resulting in increased quantity of steam. With the steam vehicle, pressure is required to make the fuel mix with air, and the burner requires more or less attention. The piping, pumps and stuffing boxes must be known to be in good order, and loss of power is usually attributed to a leak or to improper fuel and water supply.

In the Stanley steamer, the motor is geared direct to the rear axle, instead of being connected by chain as in most other forms. The light weight of the Stanley steamer, and also the Baker electric vehicle contribute much to the high efficiency shown by these light carriages.

Steam vehicles differ principally in the type of boiler, there being two general kinds, the fire tube, of which the Stanley is best known, and the flash or generator, of which the White is the principal exponent. Burners, engines and their arrangement vary also.

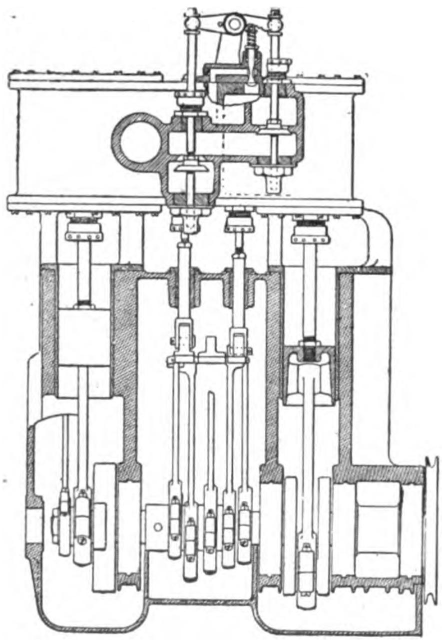


Fig. 8. Diagram of White Steam Engine.

Variations. Since, however, the majority of present day autos are gasolene vehicles, it will suffice to describe in them, most of the details that enter the auto of to-day. Besides the variations in the body, such as single or double seat, folding seat or detachable, open, with top or enclosed, side or rear entrance and many similar variations, there are two kinds of motors, two-stroke cycle and four-stroke cycle; two varieties of cooling, air and water; three locations of the mechanism, front, midway and rear; several forms of transmission, such as belt, friction, chain, planetary gear, sliding gear, individual clutch, and many variations including combinations of hydraulic and electric systems. There are two largely-used methods of ignition, with several accepted sources of electric current, viz., the jump and the contact spark; with primary batteries, storage batteries, magnetos and dynamos for supplying the electricity. Since, however, there are several hundred parts required to make up a motor vehicle, it seems best to describe these parts under various headings rather than attempt a general description which cannot be other than confusing.

The motor vehicle is commonly considered as a combination of a motor and vehicle with such other parts as are needed to make the combination operative, and in this connection the motor is described first. Since, however, vehicle motors are but modifications—usually

light and of high speed—of motors long used for stationary work, it will not be necessary to include here so complete a description as would otherwise be the case, since this information can be obtained in text books treating directly of the motor.

THE MOTOR

The theory of the gasolene motor is that a mixture of air and gasolene vapor is drawn into the cylinder of an engine and ignited, after which the pressure, due to the expansion, is caused to perform work in propelling the vehicle. The essential parts are the *cylinder*,

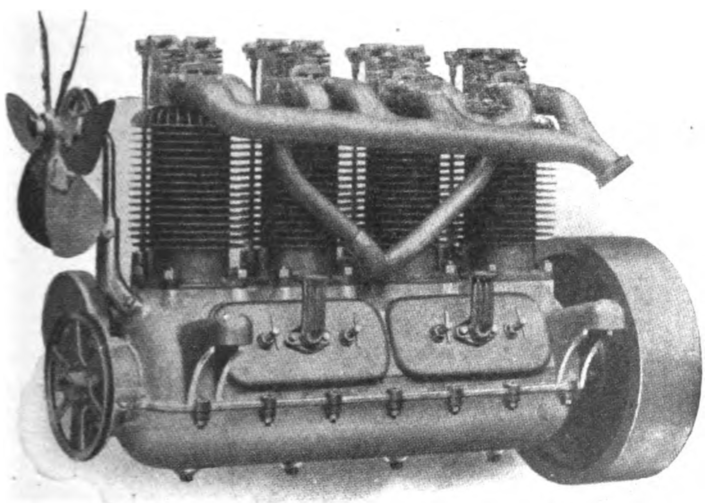


Fig. 9. Four-Cylinder Gasolene Engine.

piston, *crank shaft*, *fly wheel*, *inlet* and *exhaust* devices, *ignition* arrangement, *vaporizer*, and means of *control*, together with important incidentals, such as lubrication and means for cooling..

Cylinder. The cylinder of the engine for auto use is usually from three to six inches bore, with stroke sometimes longer, sometimes shorter, but quite generally the same as the bore. Cast iron is the usual material from which the cylinders are made, and provision for cooling, such as a water jacket, is usually cast integral with the cylinder, although quite frequently affixed in the form of a sheet metal jacket or fins after the cylinder is machined. These cylinders may be attached to

the crank case or formed with part or all of the crank case in one piece. Each method of construction has its followers and each has its advantages, according to the design of motor, crank shaft and similar parts. In motors of the type first used on DeDion tricycles, the flywheels were disks enclosed in the crank case and forming the crank sides, and since they practically filled the crank case, it was necessary that this be made in separable halves. The separation was in the plane of the crank rotation, which permitted each half of the case with its long, hardened and lapped but nonadjustable bearing, to be removed by sliding off opposite ends of the crank shaft. The cylinder was held to this case after the halves had been brought together, by screws or bolts. In many instances the head of the cylinder was held against the cylinder end by the same bolts, so that the cylinder was actually clamped between the head and the case. This design employed a cylinder open at each end, making a quite simple casting and facilitating machining.

Other cylinders are built with a simple head screwed in position, and with the ports on the sides of the cylinder instead of forming part of the head. Air-cooled cylinders are most frequently provided with circular flanges spaced one to three times their thickness apart, and rising above the cylinder wall from two to ten times their own thickness. In some cases these flanges are of sheet metal of great conductivity, as copper, forced tightly upon the smooth wall of the cylinder, or they are of smaller pieces attached by calking, clamping or other effective form of contact in or to the cylinder wall. It is essential for good results, that the cylinder should be true, particularly when hot, for if it is not truly round, and practically parallel throughout its length, the piston rings will not fit, and will not retain the gases which, leaking past the piston, leave their heat in the cylinder walls, blow away and burn up the lubricating oil, and cause excessive heating, pounding, loss of power, premature ignition and even cutting of the metal surfaces, destroying both piston and cylinder.

Valve Ports. The most common arrangement of the ports employs a pocket or passage at one side of the cylinder head in which the valves and frequently the sparking parts are placed. The exhaust valve is the nearest the crank shaft, with its stem extending toward the crank shaft where it is conveniently operated upon by the cam on the half time shaft which lifts the valve every second revolution,

as is required in a four cycle engine. The inlet valve is placed with its stem in the same axial line but projecting in the opposite direction, and is held closed by a spring and opens by the suction of the piston. By this arrangement the cool incoming charge strikes the exhaust valve and sparker parts and much reduces the temperature. Burnt gases are carried out of the pocket, leaving a fresh combustible mixture therein which contributes to certain ignition.

Recent designs have employed double cam shafts on opposite sides of the motor with valve pockets likewise on opposite sides, the inlet valve being mechanically opened, and arranged the same as the exhaust valve. These double pockets increase the wall of the compression space and therefore the loss of heat, and lessen the economy.

To avoid this increased wall surface of the compression space, many constructors now place the valves in the head of the cylinder with their stems projecting away from the crank shaft, and operate the valve by rocker arms, or place the cam shaft beyond the cylinder head and drive it by chain and sprockets instead of gears.

Whatever the form of cylinder and fittings, it is essential that there be good compression, or, in other words, that the contents of the cylinder be not allowed to escape. To test the compression, turn the engine by hand until the piston comes against the contained gases as against a strong spring, and judge by the length of time that this resistance continues as to the rapidity of the escape. A tight cylinder properly lubricated ought to resist a pull on the starting crank for a minute or more and should require considerable effort to force the engine past the compression. The operator should distinguish between high compression and good compression. If the clearance at the head of the cylinder on the compression dead center is small, the engine is known as "high compression" and if turned quickly, the resistance will be high, even though the valves or piston rings may be leaking and the compression therefore not good.

Faulty Compression. If the compression is faulty the escaping gas can usually be heard, announcing its escape by hissing. The point of escape must then be found and will usually be at the exhaust valve, for the inlet valve, being kept cool by the incoming charge, seldom needs attention. If the passages can be opened, a candle flame will, by its flickering, indicate the leak, to remedy which the valve must be removed and ground. Grinding a valve consists in oscillating it upon

its seat until the high spots are worn down, so that the valve bears equally and fully all around, thus making a tight joint. Flour emery mixed with oil is usually used, but a tighter and smoother job may be secured by finishing with powdered glass or sharp sand like the powder from the water-trough of a common grindstone.

If the leak is around the piston rings, new rings or newly fitted pistons may be needed. To avoid damage to the piston or cylinder, the operator should stop immediately if the engine begins to pound, smoke, or lose power, and he should determine the cause of the trouble before proceeding. Lack of water, a broken belt on the cooling fan, or lack of oil will usually be found causing the trouble.

Piston. The piston is the moving part which fits into the cylinder and against which the explosive pressure is exerted by the burning gases. Pistons are usually from one to two times their own diameter

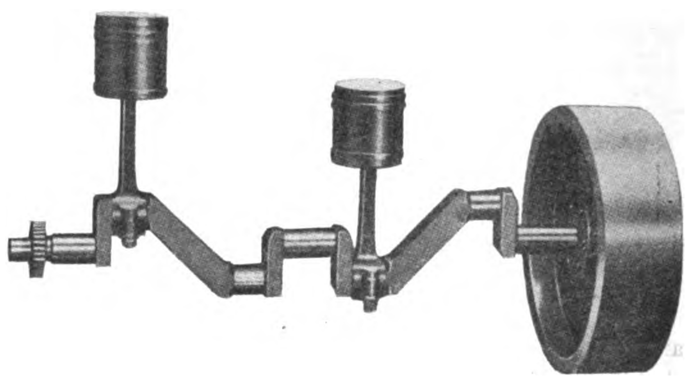


Fig. 10. Pistons and their Connections with Crank Shaft.

in length and are provided with two to four rings at the head and and occasionally with one ring at their open end. They are unlike steam engine pistons in that the pressure is taken on the head end only and that they serve as cross heads, having the connecting rods attached to wrist pins fitted generally about midway the length of the piston. This wrist pin ordinarily passes through the piston walls, lugs or enlargements being provided interiorly therefor. The wrist pin is usually fixed in the piston and the end of the connecting rod has a bearing thereon, although in some cases the pin is fixed in the end of a rod and takes its bearing in the piston, by which means a larger bearing surface is secured, and removable bushings are fitted in from the out-

side of the piston, as in Rambler autos. The head of the piston is quite commonly flat, but is frequently concave as in the Duryea, or convex as in the Autocar, and these forms are stronger and lighter than the flat head. The interior of the head is sometimes provided with radiating webs or pins as in the Frayer-Miller. The piston rings are usually of cast iron machined to a diameter larger than the diameter of the piston and then cut so as to be compressed to the cylinder diameter, which leaves them with a tendency to open and causes them to fit closely to the cylinder wall. They should be fitted carefully to their grooves in the piston, and it is particularly important that their sides be carefully fitted to the sides of the groove, so as to make a gas tight joint and prevent the escape of the gas under the ring. Two rings are often fitted in a single groove with their joints in different positions, and a third ring is sometimes placed underneath, which also serves to close the joint. Various joints are used, but a plain cut of 45 degrees or two perpendicular cuts from opposite sides, each cut being on opposite sides of a dividing line, are sometimes used, making a lap joint that is regarded as superior to the diagonal joint. Care should be taken in removing and replacing piston rings not to spring them harshly, for they will seldom return to their original shape if much abused, and if they do not fit the cylinder they will not serve their purpose properly.

Connecting Rods. The connecting rod attaches the piston to the crank shaft, and since auto engines are desired to be compact, these rods are 1½ to 3 times the piston throw. They are generally of I-beam section, so as to resist the alternating stresses to which they are exposed, but are frequently of U-section; particularly in horizontal engines, so that they may catch oil and direct it into the bearings and thus assist in efficient lubrication. Connecting rods are usually made of forged steel, but steel castings and bronze castings are sometimes used. The wrist end is very frequently solid and fitted with a bushing for the wrist pin, but in many forms this end is provided with a lug at one side, split and drawn together for adjustment by a screw. Occasionally a removable cap is fitted. At the crank end the removable cap is the more common construction. Sometimes this cap is hinged at one side and

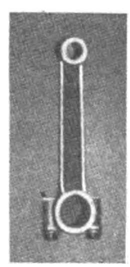


Fig. 11. Connecting Rod.

adjusted by a single screw at the other. Bushings of Babbitt metal are very commonly fitted at the crank end.

Crank Shaft. The crank shaft is usually of a high grade steel and is frequently hardened and ground. Bearings are provided at short distances apart, frequently between all cylinders, and seldom if ever farther apart than is required to bring two cylinders as close together as possible. This large amount of bearing surface contributes to long life, and also supports the crank and thus prevents danger of damaging the bearings by strains or damaging the shaft. A wide variety in shafts is found, depending upon the type of engine, the number of cylinders, the class of bearings, and the objects of the designer. Where ball bearings of the nonadjustable type are used, the crank

Fig. 12. Crank Shaft.

shafts have been built up in short pieces, so as to permit putting the ball bearings into position, but this method is not very common. Shafts are frequently made hollow, both in the shaft proper and in the crank pin, for by so doing nearly one fourth the weight can be saved, with little decrease in strength.

The common method of attaching the fly-wheel to auto crank shafts is by means of a flange integral with the crank instead of keyed on, as in most other engine practice. The web of the fly-wheel is bolted to this flange by an ample number of bolts to hold it securely and yet permit easy removal. The saving in space lengthwise of the crank shaft makes this method of particular value in a vehicle like the Duryea, where the width of the body limits the length of the shaft available for the engine and transmission gear, particularly in connection with multiple-cylinder engines. The crank shaft is usually provided at one end with ratchets for starting purposes, with a gear for driving the cam shaft and any other fittings such as pump or magneto, while at the other end the fly-wheel and the connections for the transmission gear are placed.

In some cases the fly-wheel is on the end of the crank shaft opposite the transmission gear, but this is not considered the best practice, because, in suddenly setting a clutch, the inertia of the fly-wheel is transmitted through the shaft to the transmission gear, causing a more or less severe strain on the shaft and requiring a stronger shaft than would otherwise be necessary. In two-cylinder engines it is customary to set the two cranks of the shaft opposite each other, or 180° apart. Other arrangements have been used but have not been found so satisfactory as this. In three-cylinder engines, the cranks are 120° apart and in four-cylinder engines they are 180° apart or the same as if two two-cylinder cranks had been joined end to end with the two outer pistons moving together and the two inner ones together. For six-cylinder engines the setting is the same as if two three-cylinders had been joined—the inner, intermediate and outer pistons respectively moving together. Three bearings for a four-throw shaft and four bearings for a six-throw is quite common practice, as is also five and seven bearings respectively. A few engines have cylinders which revolve around a stationary crank shaft, and in these a single throw shaft is usually used, the Adams - Farwell having five connecting rods attached to the single crank pin. When the engine "knocks" at speed, whether hot or cold, a loose connecting rod or loose fly-wheel should be looked for, lest the shaft be broken by the constantly repeated blows.

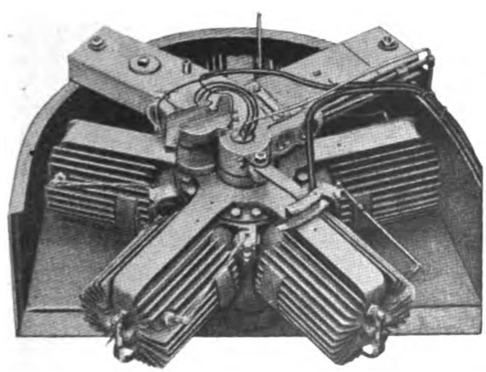


Fig. 13. Gasolene Engine with Revolving Cylinders

Fly-Wheel. The fly-wheel of a gas engine is a sort of necessary evil. Since in a four-cycle engine there are three idle piston strokes to one working stroke, a fly-wheel is necessary to store up the energy of the one working stroke and carry the engine steadily through the three idle strokes. In a single-cylinder engine this fly-wheel must be of considerable size, weighing when used with a cylinder of 4½ x 4½ inches, 150 to 200 pounds. With two cylinders there are double the

number of explosions and consequently only one idle stroke between the working strokes, so the fly-wheel can be reduced in weight nearly one half. With three cylinders the working strokes follow each other with but one sixth of a revolution intermission and a 55-pound fly-wheel, as used on the Duryea, after a long experience with a variety of weights, serves nicely. A three-cylinder engine may be run without any fly-wheel whatever, but this is not considered practical, although a 25-pound fly-wheel, 18 inches in diameter, serves quite well in a 12 H. P. engine, for all except very slow speeds, at which the separation of impulses becomes so pronounced that is is disagreeable.

In order that the weight may be as little as possible, the fly-wheel is made of the largest practicable diameter and the weight is kept as fully in the rim as may be. In many cases the interior surface of the fly-wheel rim is used to form the clutch surface, while the magneto pulley or pump pulley is driven by friction against the outer surface, which in some cases also serves as the driving face for a fan belt. The spokes are screw-propeller shaped in some instances, to throw air for cooling. In others the face of the wheel is a plane and is used for a friction disc, with the edge of another disc bearing against it, and shiftable to vary the speed of the driven disc.

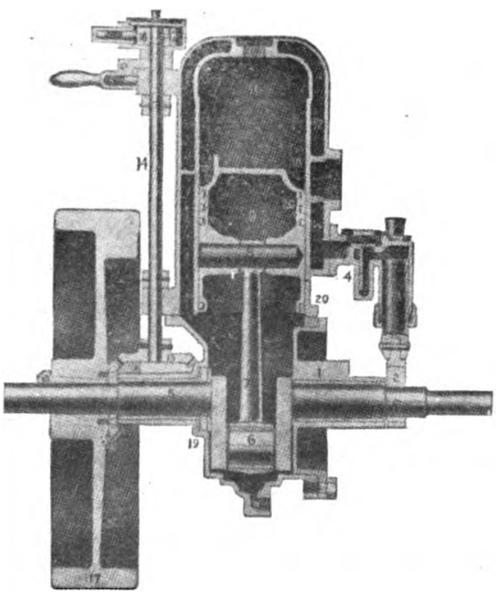


Fig. 14. Section of Gasolene Engine, Showing Enclosed Crank.

Crank Case. In a two-cycle engine the crank shaft is usually enclosed in a tight case arranged to hold pressure to the amount of 5 or 10 pounds under running conditions, although strong enough to hold an explosion which may sometimes occur in the crank case. The cylinder is provided with ports uncovered by the piston at one end of

the stroke, which serve to exhaust the burnt charge and admit the new charge from the crank case into the cylinder proper. Most two-cycle engines are further provided with an inlet port uncovered at the opposite end of the stroke to admit a new charge from the vaporizer into the crank case, where it is compressed by the return, ready to pass into the working end of the cylinder on the opening of the transfer port. Some two-cycle engines have valves, usually of the poppet type, to pass the unburned gases, but these are generally automatic and do not add much complication.

In the four-cycle engine, the cylinders serve the double purpose of containing the working charge during one revolution of the shaft, and the new charge during the next revolution, thus avoiding the use of the crank case as a charge-containing chamber, but requiring two revolutions instead of one per explosion as in the two-cycle engine.

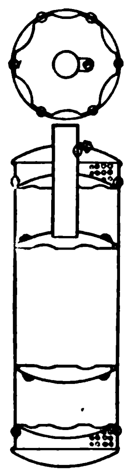


Fig. 15. Diagram of Muffler.

Valve Action. To accomplish this result with a single cylinder, valves are used both for inlet and exhaust, which are operated ordinarily by a half-time shaft fitted with cams arranged to open their respective valves during substantially one stroke of the four strokes forming the cycle. The exhaust valve is opened about 20 to 25 degrees ahead of the crank shaft dead center, and closed at the opposite dead center one stroke later. The inlet valve immediately opens, and it closes at the end of the next stroke one revolution after the exhaust valve opens. Both valves remain closed during the compression and working strokes.

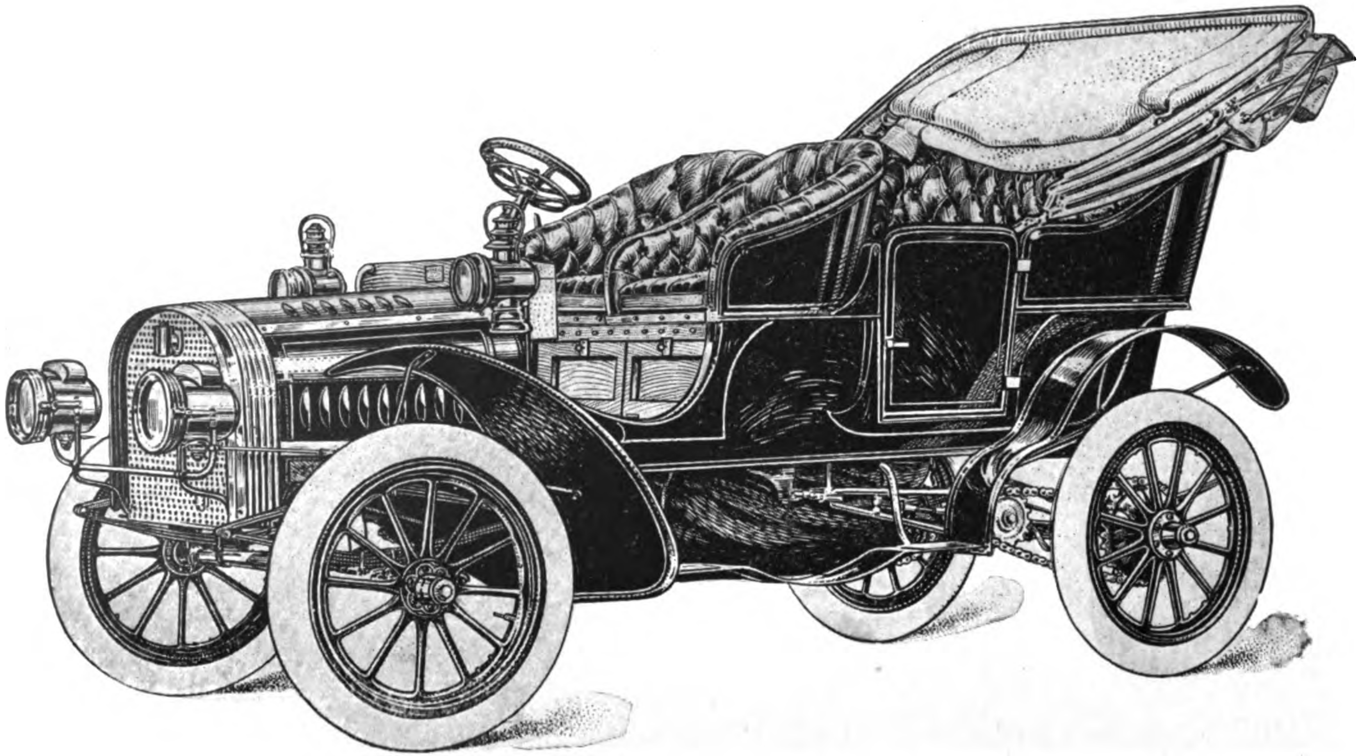
These valves are variously placed according to the ideas of the designer. A common arrangement places them in the head of the engine with stems projecting from the crank shaft, in which position they are usually opened by rocker arms and plungers actuated by cams on the half-time shaft located in the crank case. In a great number of instances the cylinder or cylinder head is provided with a port passage or pocket on one side of the cylinder head and the exhaust valve is seated therein with its stem projecting toward the crank shaft. The inlet valve may be similarly seated in a similar pocket, or in the same pocket with the stem projecting in the opposite direction. An

advantage of having the inlet valve in the same pocket is that the incoming charge cools the exhaust valve and also the sparking parts, which are frequently located in the same pocket entering through the side thereof, or as in the Duryea, through the exhaust valve stem. It is evident that one pocket requires less cylinder wall than two and therefore loses less heat to the cooling system.

The size of the valves depends much upon the speed required and should be quite large if a high speed is desired. Very satisfactory practical results are obtained by making the exhaust valve one third the piston diameter and the inlet valve one fourth, although to save variety of parts, some designers use the same size valves in both instances, but do not lift the inlet valve so high. Variable lift valves are much in favor because this prevents unnecessary valve movement with consequent wear and noise. In some cases this variable lift is secured by introducing a wedge between two parts of the lifting mechanism, and in other cases by holding the valve against more than a limited lift in response to the suction of the piston, as in the variable lift inlet valves of the Duryea.

Auxiliary Exhaust. In order to get rid of the excess heat, and relieve the regular exhaust valve of part of its duty, some engines are provided with an auxiliary exhaust, consisting of a port through the cylinder wall uncovered by the piston at the end of the working stroke, as in the Fredonia and Franklin machines. It is considered advisable to provide this port with a check valve to prevent back pressure from the muffler from re-entering and lessening or possibly igniting the new charge; although this is probably not so necessary in single or double cylinder engines. Many designers consider the auxiliary valve as an unnecessary complication, used only where the regular valve is inadequate.

Muffler. Connected with the exhaust opening by piping of convenient length, is the muffler, consisting usually of several chambers generally cylindrical, and having walls of sheet iron. This device has usually several times the capacity of the cylinders, which permits the exhaust gases to expand considerably and exposes them to the cool walls, thus reducing their volume by cooling, so that as they escape to the atmosphere they make much less noise than if permitted to escape without the intervention of the muffler. Multiple passages as well as multiple chambers are usually provided, and the silencing



SURREY TYPE AUTOMOBILE WITH 20 H.P. TWO-CYLINDER HORIZONTAL ENGINE.
Thomas B. Jeffery & Company.

effect seems to be largely derived from interference of the sound waves and gaseous impulses.

Most mufflers offer some back pressure, but if of sufficient size, and provided with three to six chambers, the exhaust of the ordinary auto engine can be silenced as effectually as other noises about the vehicle, with so little back pressure as to not be perceptible in the propulsion of the vehicle if a cut-out is used. Mufflers sometimes clog with soot and dust and do not permit free escape of the gases, particularly at high speed. The large part of the burnt charge remains in the cylinder and prevents the entrance of a new charge, with consequent failure to produce power. Muffler explosions are due to missed fires in the cylinders, which allow the unburned charge to pass to the muffler, where it is ignited by the next exhaust and explodes quite noisily, and sometimes to the damage of the muffler. Muffler cut-outs are often used on hills or where great power is needed, and they avoid any back pressure from the muffler.

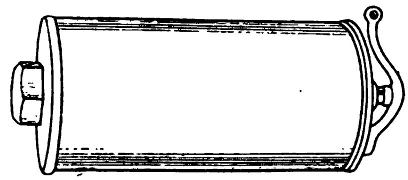


Fig. 16. Muffler and Cut-Out.

Vaporizers. Connected to the inlet ports is the device for mixing the liquid fuel, commonly gasolene, with the proper proportion of air to make an explosive mixture. Formerly this was done by a device for passing the air through the liquid contained in the tank, termed a carburettor, and while good results were obtained therefrom, it was more delicate and not so satisfactory to adjust for varying weather conditions as the devices now used. Present-day devices are modifications of the well-known atomizer used for perfume and medicine sprays, and might better be termed mixers or atomizers than carburettors. Since, however, the liquid after being sprayed, is intended to be vaporized before ignition, a common and correct term for this device is vaporizer. There are many modifications of this device but in general it consists of a small gasolene chamber in which the level of the liquid is controlled more or less perfectly, by a float, the chamber being vented so as to permit admission or abstraction of liquid without establishing a compression or vacuum.

From the float chamber a small passage, usually controlled by a needle valve, leads to the spraying tube, which is so placed that the air

drawn in by the suction stroke of the engine must pass the point of the tube, and in passing, suck out and spray the gasolene in the required manner. In order to give the air greater speed and a more powerful

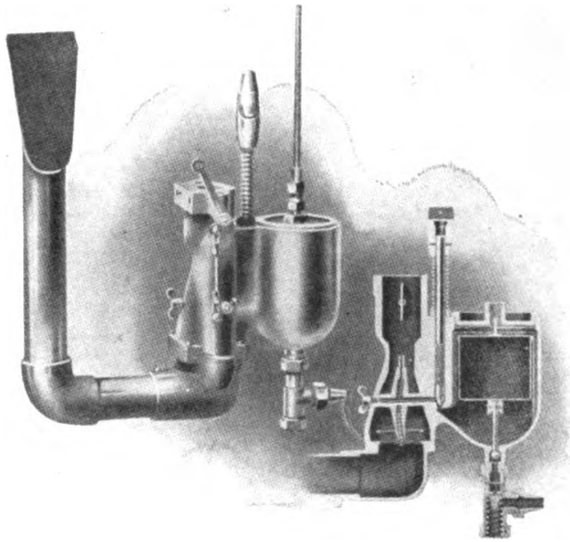


Fig. 17. Carburettor.

effect, it is customary to make the air tube contracted at the point where it passes the spray tube, although very satisfactory vaporizers have been produced without this modification. Since at high speeds the liquid gasolene flows more than proportionately fast as compared

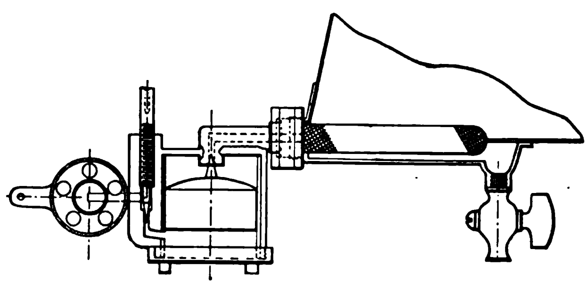


Fig. 18. Sectional View of Carburettor.

with the air, it is quite common to provide a light valve, spring closed, to be opened by the increased suction as the speeds increase and to admit air in proper quantity to compensate for the increased amount of gasolene. This valve in some forms is actuated by a large dia-

phragm, as in the Krebs, and is sometimes provided with a dash-pot.

In some vaporizers the air and gasolene openings are varied by the throttle, which is also varied to control the speed of the engine, and since the screw threads, or devices controlling the variation, may be made as desired, a fairly constant quality of mixture may be secured from vaporizers of this type, subject, however, to the fault that if the throttle is open wide but the engine running slowly, the adjustment intended for high speed will be in operation at low speed, and thus is not so satisfactory as an automatic suction-operated arrangement. The early Kingston carburettor was of the throttle-controlled type. In still another type, of which the Duryea is an example, the air-flow passes through an opening fixed in size except for starting, but the gasolene-flow is varied by lowering the level in the float chamber at high speeds. This is accomplished by the use of a chamber slightly larger than the float, so that little or no reserve gasolene is carried, and this is drawn out immediately at high speed, causing the float to fall and open the passage into the float chamber. The float is provided with a long taper point which requires a considerable movement of the float, in obedience to the considerable variation of the gasolene level, in order to supply the amount of fuel needed at high speed.

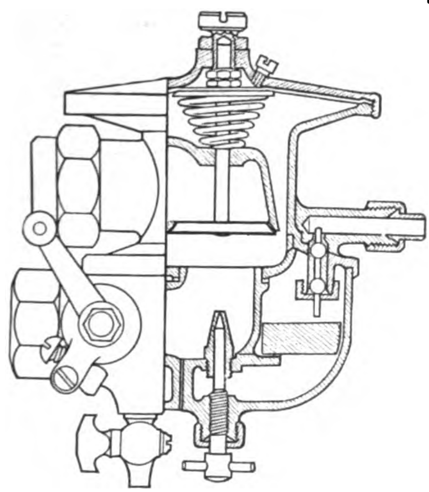


Fig. 19. Automatic Compensating Carburettor.

In still another form, invented by Dunlop, of pneumatic tire fame, the gasolene passage is impeded by a saw-toothed wire, against which teeth the gasolene, at speed, impinges with such violence as to obstruct its flow and lessen the amount passing from the spray tube. Still another form of mixing device does not use the float chamber, but admits the air and gasolene through proportionate valves closed by a spring and opened by the suction of the motor with consequent

admission of proportionate amounts of liquid and air. The original Winton and the Lunkenheimer generator valves were of this kind.

Vaporization. The vaporization of a liquid requires heat, which, in the case of a gas engine vaporizer, is usually obtained from the air with the result that the temperature is decidedly lowered where the vaporization takes place, viz., between the spray tube and the engine, principally near the spray tube. If the atmosphere contains much moisture, this cooling effect causes a deposit on the walls of the vaporizer or its tubing, which is frequently frozen, forming slush or white frost, sometimes to such a degree as to actually close the passage and prevent further formation of proper mixture, with consequent stoppage of the engine. To prevent this and to insure a more homogeneous mixture, heat is usually supplied by drawing the air from near some heated portion such as the exhaust pipe or exterior walls of the cylinder, or by applying heat to the outside of the vaporizer or pipes by directing some of the exhaust gases against them, or by surrounding the parts with warm water from the water jacket. No method secures absolutely perfect results, for atmospheric conditions vary so widely from day to day that only constant readjustment can meet the varying conditions.

Vaporizer troubles are usually due to improper adjustment, the mixture being either too poor or too rich. If the engine will run, the adjustments can be varied and the result noted, while over-rich mixtures will be quite apparent by the odor of carbon monoxide in the exhaust. If the engine will not run, test the mixture in the cylinder by removing a spark plug or peep cap and applying a flame, being careful not to get fingers or face in front of the opening. If the mixture burns bluish with little violence, it is too poor, but if it burns yellow and slow, it is too rich. A proper mixture explodes with a violent outrush of gas.

Frost in the air tube will so obstruct the passage as to prevent the entrance of a new charge and produce loss of power much like a choked muffler. A little hot water will quickly warm the pipe. Water or ice in the gasolene will cause trouble unless removed. The water frequently manifests its presence on rough roads, and a drop of water in a passage—which will not obstruct the flow—has, when frozen, completely shut off the gasolene. Dirt particles also must be guarded against.

Excess Cooling. Since the auto engine is a heat engine it is desirable that it be as hot as is permissible, in order that the heat may be utilized for work instead of passing into cold walls and being wasted. It is well known that a cold engine runs with little power until warmed up, and while part of this lack of power may be due to the stiffness of the lubricating oil,—since this is intended to resist a high heat and must be of high fire-test and of considerable body—much of the lack of power is due to the cooling effect of the cold walls, which absorb the heat from the burning explosive charge and reduce the pressure that, with hot walls, would be expended in doing active work against the piston. Tests have been made which show that a very perceptible increase of power results from the use of hot water for cooling instead of cold water, and stationary engineers who have permitted a flow of water through the water jacket so rapid as to keep the jacket and walls cool enough to not be uncomfortable to the hand, have found a very decided increase in power when the water was caused to flow more slowly and leave the jacket substantially at the boiling temperature.

It is now generally admitted that a temperature slightly below boiling is most satisfactory where water is used for cooling; for if the water does not boil, no steam is formed, and no parts in the water jacket are left without water, with possible danger of overheating. These facts, now well-known, prove the theory that a heat engine should be run hot in order to give most efficient results, and it is the aim of designers to so design their productions that no parts shall be over-hot but that all shall have as high a temperature as is permissible. The principal limitations are premature ignition and faulty lubrication.

Premature Ignition is objectionable because of the negative work done on the piston before it passes the dead center, which not only results in lost power, but usually in a decided knock or pound, annoying to the passengers and destructive to the bearings. Since a poor mixture ignites less easily than a rich one, premature ignition can be frequently lessened and sometimes avoided by varying the quality of the mixture—a proceeding which also adds to the economy. Since compression heats the explosive charge, nearly proportionate to the amount of the compression, an engine designed to run hot should have a large compression space with consequent low compression. The increased economy of the less rich mixture in conjunction with the

hot cylinder walls largely balances the loss of power, due to the lessened compression and since the engine with low compression runs steadily with a smaller fly-wheel, there is a perceptible saving in weight in a motor vehicle and consequently less need of power.

It is also apparent that with a high compression and a small compression space, the pressure at the beginning of the stroke is very high but falls rapidly because the length of the stroke is quite large as compared to the size of the compression space, whereas with a low compression the initial pressure is not high and the compression chamber is of large volume as compared with the length of stroke, so that the pressure is reduced less rapidly and the result is more nearly like that given by a steam engine than is the action in a high compression cylinder.

Because of these facts a low compression cylinder, rather large for the power required, but because of the low compression, light in all its parts, including fly-wheel, and designed to run comparatively hot, is considered best for auto work by many good authorities. It has been frequently noticed that an air-cooled engine, will, for a short period, develop more power than a water-cooled, and this is explained by assuming that the walls become much hotter than the temperature of boiling water, on which account the engine is more efficient up to and until the point of overheating is reached. After this, loss of power occurs, either because of premature ignition or lack of lubrication, or possibly, because at very high temperatures, the cylinder walls or the piston warp sufficiently to no longer fit each other and thus permit the escape of the gases with consequent loss of power. While higher temperatures may be with advantage used in future, it seems safe to assume that in the present state of the art, a temperature not greatly in excess of boiling water, is most preferable in present auto engines.

Lubrication. Faulty lubrication of an engine cylinder may be due to the improper fire test of the oil, to improper methods of applying the oil to the surfaces requiring lubrication, or to improper fits between those surfaces, which permit the escaping gases to blow the oil away from the surfaces, leaving them dry and therefore increasing their heat, both by the friction of the nonlubricated parts and by the heat of the escaping gases which is absorbed by the parts. It is now pretty generally recognized that auto cylinders require oil of the high-

est quality, and that cheap and dirty oil sometimes sold as gas engine oil, is not suited for this work.

An oil suited to steam engines using superheated steam, will in almost all instances, give excellent satisfaction in auto engines. The makers of the vehicle will gladly advise what oil should be used in connection with their product, and when a good oil is once found, it is wisdom to continue its use. If an oil is too thin it does not protect the metal surfaces properly and does not make a good packing nor properly assist the rings in holding the pressure. If of too low fire-test, it boils away as a blue smoke or vapor and leaves the surfaces dry, frequently causing them to cut, and sometimes ruining the cylinder or stopping the motor. A sudden loss of power without apparent cause may, with good reason, be looked for in the cylinder, since lack of lubrication makes a great difference in the friction of the piston, even though the parts are not cutting or have not seized. An excessively thick oil with needlessly high fire-test has no disadvantage except that being stiffer when cold, the engine is more difficult to start. Such oils are decidedly more economical because they wear longer and need be fed less rapidly. Good auto oils usually have fire-tests ranging from 600 to 800 degrees.

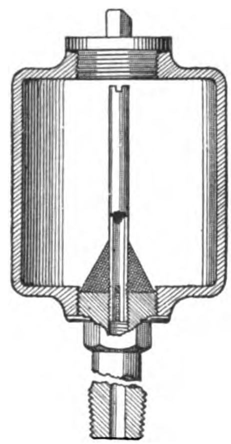


Fig. 20. Lubricator.

If for any reason, proper oil cannot be had, an oil of lower fire-test can frequently be used, but it must be fed in larger quantity and more carefully watched to make sure that it is serving its purpose.

Water Cooling. Consideration of the above facts will show the importance of proper cooling, and something of the loss due to excessive cooling. In a water-cooled engine, the water being unconfined, cannot become hotter than 212° and may, with little trouble, be kept nearly at this point, which is admitted to be most satisfactory, so far as present experience goes. Further, since water in boiling absorbs a great volume of heat, commonly termed latent heat, in its conversion into steam, it is especially adapted to the work of cooling. An increase of work on the part of the engine, with consequent increased development of heat, simply increases the rate of boiling without in-

creasing the temperature appreciably, and thus avoids warping the cylinder wall or vaporization of the lubricating oil.

A most efficient cooling system consists of a tank or reservoir of water above the engine, piped to enter the water jacket on the underside and to return from the water jacket to the tank on the upper side of the engine, which return carries off any steam that may be formed in the water jacket, which steam being lighter than the water, causes the water with which it is mixed to move rapidly upward out of the water jacket and to be replaced by cooler water from the tank. This method of circulation is known as the natural or thermo-syphon method, and is preferred by many designers because of its simplicity. When it is not convenient to use natural circulation, a pump, driven by the engine, is introduced in the circuit and forces the water rapidly enough to nearly or quite prevent boiling under extreme conditions. A forced circulation, however, is not so good as the natural because it is not self-regulating, and therefore if it is fast enough to meet the needs of the engine under extreme conditions, it is usually too fast under ordinary conditions, and results in keeping the temperature of the water in the water jacket much below the boiling point and therefore below the point of greatest efficiency.

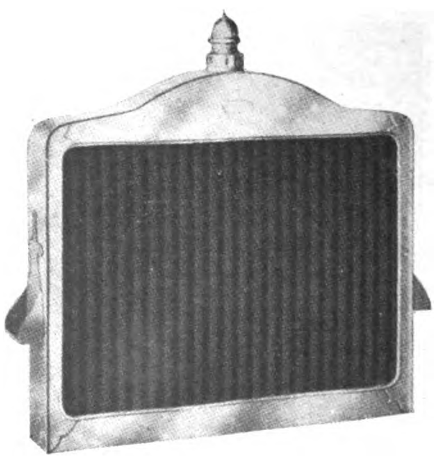


Fig. 21. Radiator.

To overcome this objection, some designers employ natural circulation between the engine and the small tank located near and above it, and employ a pump with radiator for the purpose of preventing the water in the tank from getting too hot to condense the steam that may pass into it from the engine. This arrangement gives the benefit of both systems with but little, if any, increased complication.

Since an auto engine of large power develops much heat, a goodly quantity of which passes away through the cooling system, it is quite evident that the water in the tank will soon become boiling hot unless

provision is made for cooling it by the air through which the vehicle passes. It was formerly quite common to provide the tank with air tubes, thus greatly increasing the amount of surface exposed to the air and permitting a more rapid escape of the heat. Other designers employ pipes either plain or with radiating fins, so as to still more largely increase the radiating surface exposed to the air. Still others make their water-tanks almost wholly of air tubes, with very small water spaces between, thus getting into a small radiator a great many square feet of cooling surface. In this form of radiator it was found that the natural circulation of the air is very slight because of the small size of the passages, so fans driven by the motor are most frequently used to either draw or force the air through these radiators at a rapid rate and with great cooling effect.

A further advantage of the air-fan in connection with the radiator is that the cooling is not dependent upon the speed of the vehicle nor the force of the wind but is varied by the speed of the motor, and therefore more nearly meets the needs of the motor than any other system excepting the natural system, first mentioned. If for example, as in hill climbing, the motor is running slowly, but with full charges, much heat is developed, but the fan also moves slowly, with very little cooling effect, whereas in the natural system, until the water begins to boil, the circulation is very slow and the more rapid the boiling, the more rapid the circulation becomes. This results in a truly thermostatic circulation, regardless of motor or vehicle speeds, due to the difference in density of the cool water in the radiator and the hot water containing more or less steam in the jacket which is sufficient to meet the requirements of some engine designs. In others, a pump to circulate the water is used.

There have been employed steam condensers in connection with the water jacket by which arrangement no water tank nor pump is needed, because the slight amount of water in the jacket when turned to steam, is condensed by the condenser and at once returned to the jacket. Practically all water-cooled engines form steam at some time, which, not being provided with suitable condensing surface, escapes from the system, thus requiring occasional addition of water. It is considered advisable to have a tank of water above the cylinder jacket, so that the cold water may condense this steam and also always keep the cylinder filled. This tank carries from two to ten gallons.

Most radiators are tubular and on the tubes are fitted and soldered disks of metal, which serve to conduct the heat from the water out to the air, which, by the passage of the vehicle, is thrown against the metal surfaces. These flanges are formed in some instances by crimping a strip of metal along one edge and winding it spirally around the tube, the crimped edge being soldered to the tube. This avoids waste of metal and makes a very efficient radiator. The height of the disk edges above the tube is usually ¼ to ½ an inch or about 10 to 20 times the thickness of the metal, the smaller sizes being most efficient.

In some cases the water tank is cooled by tubes passing through it, which permit a flow of air. These tanks vary from those of large water capacity, having a half dozen or more one-inch tubes, to tanks of small contents completely filled with tubes, either square or round, ½ inch in diameter or less, by 3 or 4 inches long. Such a device is called a cellular or honeycomb radiator, because the tubes suggest the cells of a honeycomb. This type of radiator contains a very large cooling surface, divides the water into thin sheets and is quite efficient, but it is expensive to make, has many joints likely to leak, and the fine passages are easily clogged, on which accounts, the tubular form is now generally preferred. The tubes may be continuous, causing the water to travel the whole length, but later forms use a number of tubes connected at their ends by heads or top and bottom tanks, and the water flowing from one end to the other, is divided, so that a small portion only flows at slow speed through each tube. This arrangement relieves the pump of much of its duty.

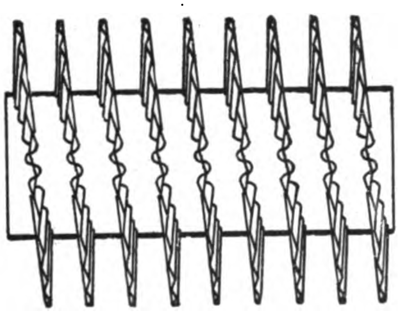


Fig. 22. Radiator with Spiral Flanges.

Air Cooling. Since in any event the heat is dissipated into the air, it is argued by many that air cooling is the most logical form, and many attempts have been made to produce successful air cooled motors. The total heat in the burning charge varies as the cube of the cylinder dimensions, whereas the wall surface varies only as the square; so it has been assumed by many that large engines are of neces-

sity more difficult to cool than small ones, and that air cooling, while applicable to small powers, is not suitable for larger ones. Others maintain, while admitting the above statement as to the total amount of heat, that the heat received by the wall from the gases in the engine must come from the gases adjacent thereto, and that on this account the wall will be little, if any, hotter in the one case, than in the other, and that large auto engines can be cooled just as readily and practically as small ones.

Since, however, the size of engines used in auto work is limited by the weight of the parts and the intensity of the vibrations set up by the explosive charge, it seems quite likely that the latter contention is practically true. It is now no longer common to increase power by increasing the bore of the cylinders, but the accepted method is to increase the number of cylinders, and it was quite thoroughly demonstrated by Knox and others, that cylinders up to 5 inches bore, of varying strokes, can be successfully air cooled.

The most common forms of air-cooled cylinders are either cast with flanges encircling them or machined out of a solid body of stock or forced on by pressure after the cylinder is machined. Other forms have the cooling flanges cast lengthwise of the cylinder. If the engine is horizontal the encircling flange permits the hot air to pass freely away, which is not the case when the engine is placed vertically, unless a fan or some means for moving the air horizontally is provided. For vertical engines using natural air circulation, the lengthwise flanges are undoubtedly best.

Many air-cooled engines are fitted with special forms of cooling surfaces such as threaded pins having one end screwed into the cylinder wall, which pins not only carry the heat outward, but because of the screw threads on their surfaces, are in contact with a large volume of air. Grooves are frequently machined into the cylinder surface, in which are chalked combs or strips of radiating metal having large radiating surface.

In all the larger motors, fans are used to direct a current of air past the radiating surfaces to insure effective cooling.

In some engines, as in the Frayer-Miller, the cylinder is enclosed in a jacket, through which air is forced and by which the air is caused to come in close contact with the heated surface with the result that the cooling is positive, is certain to be effective where needed, and is

largely proportioned to the needs of the engine, because the blower which supplies the air is driven by the engine. In air cooling, however, unlike water cooling, there is no fixed temperature point and there is, therefore, much more variation in the walls of the cylinder, with con-

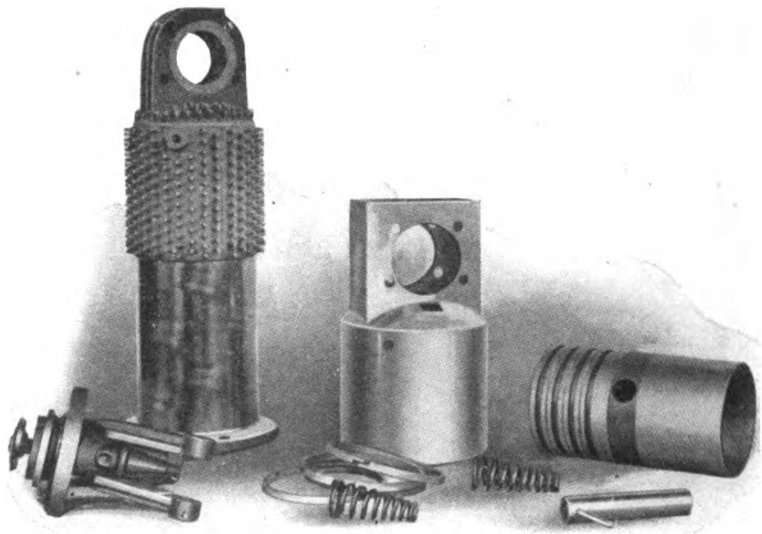


Fig. 23. Frayer Miller Engine Parts.

The aluminum jacket slips down over the cylinder head, the valves being put in from opposite sides. Air is forced down from the top of the jacket passing equally to all sides, cooling the cylinder without warping.

sequent possible warping, than is found in a water-cooled motor. This variation is believed by many to shorten the life of the engine and increase its troubles, while others argue that the avoidance of the water system more than makes up for the lack in this respect.

CHANGE-SPEED DEVICES

Second in importance only to the motor is the mechanism for conveying its power to the rear axle, or to the propelling wheels. This mechanism consists usually of first, a change-speed device by which the ratio of motor revolutions to rear-wheel revolutions is varied to meet the varying road conditions, such as hills, mud, sand, snow, crowded traffic or clear level roads; second, of a transmitting device such as a shaft, chain, or chains, or belts between the change-speed gear and the rear wheels; and third, of a balance gear often called a

differential, or its equivalent, by which the power is divided and caused to drive both wheels, while permitting freedom for the purpose of turning corners.

Change-speed gears are of many varieties, of which the most common are planetary, sliding gear, individual clutch, friction, automatic and several others, combining more or less of the various features found in these forms with possibly slight variations, such as magnetic, pneumatic or hydraulic clutches. Few subjects offer a greater field for ingenuity than change-speed devices, and many forms not worthy of description in the limited space available, have been tried and found reasonably satisfactory.

Planetary Gear. The planetary gear was the first form to be largely used in America, being first regularly employed on Duryea vehicles in 1898 and afterward adopted in the Olds runabout and by its many imitators, as well as in the Cadillac and Ford machines, in all of which it is still found, as well as in many others. In its original form it employed a spur driving gear attached to the crank shaft. Meshing into this was a planetary pinion carried by a stud projecting from a frame journaled on the crank shaft end, which frame carried the driving sprocket. Meshing into the pinion, was an internal gear concentric with the crank shaft, and the device was provided with three clutches, one for locking the parts together, so that all would revolve with the crank shaft, forming direct drive on the high gear; another for holding the internal gear stationary while the pinion rolls around inside it, carrying the sprocket forward at low speed; and a third for holding the pinion frame and causing the sprocket to be carried by the internal gear in a reverse direction as the pinion revolves. (The sprocket having been first released from the pinion frame.)

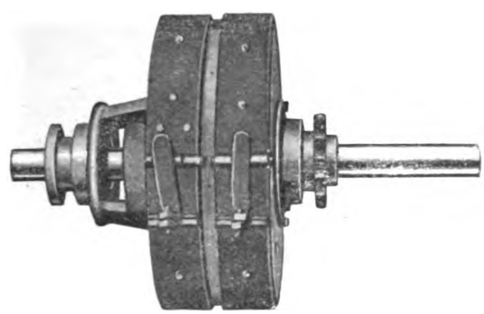


Fig. 24. General View of Planetary Gear.

These clutches were operated separately, only one, as a rule,

being engaged at a time. A single operating lever was usually employed for high and low speed, while a second lever was used for the reverse. Two to four pinions were employed instead of one, which gave added strength without requiring additional room, and thus permitted the gears to be of much narrower face for a given duty than would have been possible with a single form. Modifications of this device employing two or more sets of gears are largely used because

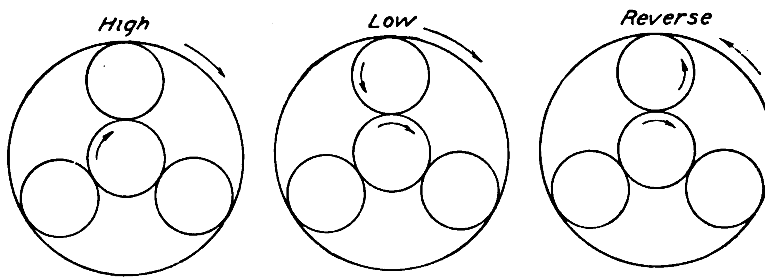


Fig. 25. Planetary Gear Diagram.

All parts locked together, gives high gear and carries the sprocket at same speed as crank shaft without friction or moving parts.

Holding the large internal gear causes the intermediates to roll forward slowly and carry the sprocket with them, giving low gear, one-third to one-fourth the crank shaft speed.

Holding the spindles of the intermediates drives the internal gear in a reverse direction, giving the reverse speed.

the original form was protected by patent, but the principle is much the same in all. The diagram herewith illustrates the action more fully. As usually constructed, the planetary system provides two speeds forward and a reverse, but some forms provide for three speeds forward together with a reverse.

Individual Clutch. The individual clutch transmission is still an older form, having been used by Duryea in '93, Haynes in '95 and by several foreign makers fully as early. This consisted usually of two parallel shafts on which were two or more sets of spur gears of different sizes but of a common distance between centers. Each set of gears was provided with a clutch adapted to cause that set of gears to transmit power at its proportionate speed when desired by the operator. For reversing purposes, sprockets and chain instead of gears were used, or one set of gears small enough not to mesh, but provided with an intermediate, were employed. The individual clutch system permits a wide variety of speeds, smooth and noiseless engagement of any speed, and is a very satisfactory system, its principal objection being the large number of clutches and the fact that all sets of gears are in

motion at all speeds. To avoid clutches some designs employ a single friction clutch and a movable key or pawl by which any gear can be locked to the shaft, and speed changes are made by sliding this key from one set of gears to the next. The strain on the small key results in its rapid destruction and forms the principal objection to

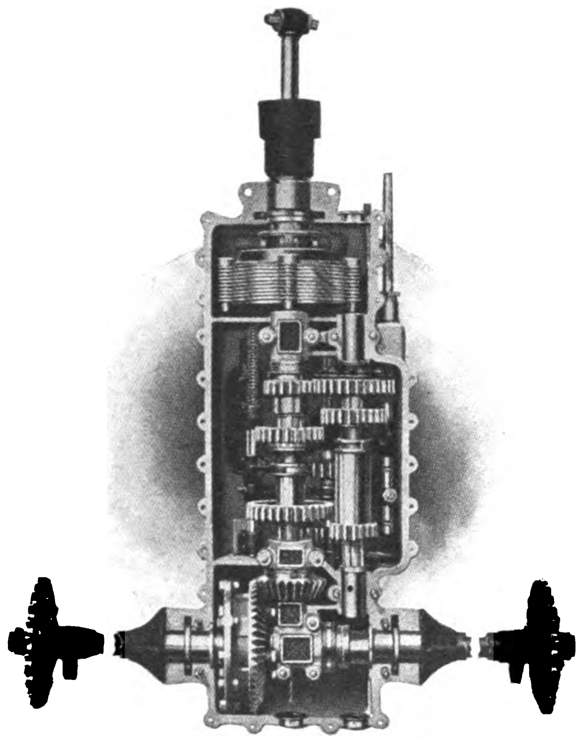


Fig. 26. Clutch, Sliding Gear and Counter Shaft.

this arrangement. Similar results are obtained by sliding the gears themselves, which although not so compact, is considered a stronger and more desirable device.

Sliding Gear. Possibly the most used form to-day is the sliding gear. This, like the other forms, is made in a number of varieties but, in general, consists of parallel shafts, and multiple sets of gears of differing proportions. On one shaft the gears are fixed, while on the other they are commonly attached to a sliding sleeve, which is either fitted to a square shaft or provided with a spline and key-way to prevent rotation of the gears without rotating the shaft, and yet permit

free movement of the gears along the shaft. The gears are placed at such intervals that when one is engaged, the others are disengaged. In operation, a single clutch, generally located in the fly-wheel, is withdrawn while the gears are being shifted, after which the clutch is allowed to engage and propel the vehicle. The ends of the gear teeth are sharpened so that they will engage each other easily and thus permit shifting from one set to another without difficulty. If the

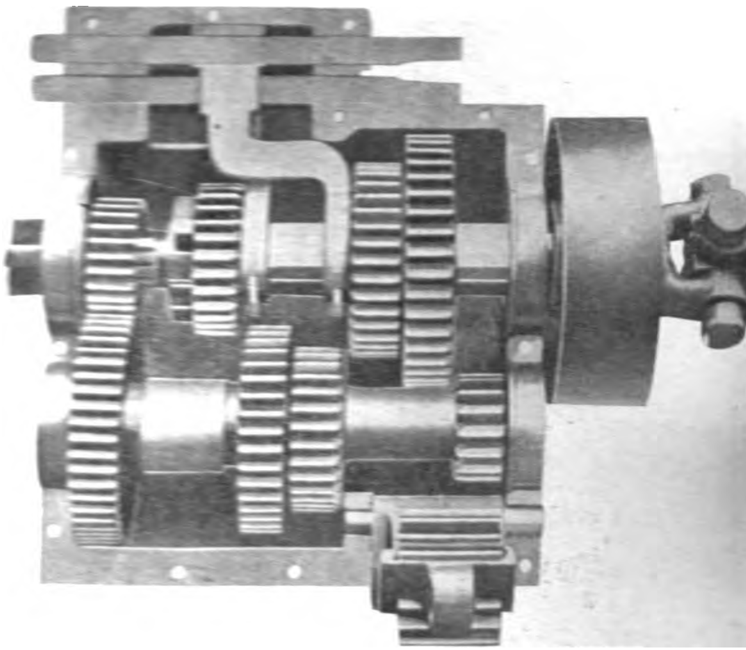


Fig. [illegible]. Sliding Gear Set.

clutch is not fully withdrawn, the ends of the teeth about to engage strike against each other, often making considerable noise and sometimes breaking the teeth.

In the better forms of sliding gear designs, the main shaft is divided in a gear box, and the power transmitted to the second shaft is, by an additional set of gears, returned to the second part of the main shaft and by it transmitted to the wheels. At one speed, usually the highest one, the two parts of the main shaft are connected by a clutch of the positive or jaw-clutch variety, while the parallel shaft with its gears is completely disengaged and stands idle. This gives a direct

LIMOUSINE TYPE OF AUTOMOBILE, 1906 MODEL
The Winton Motor Carriage Co.

drive, free from needless friction and is considered quite advantageous. In some forms, two of the sliding gears are on one side and two on the other. This, of course, requires two shifting forks in its operation. Other forms employ a shifting fork for each gear and a selective means

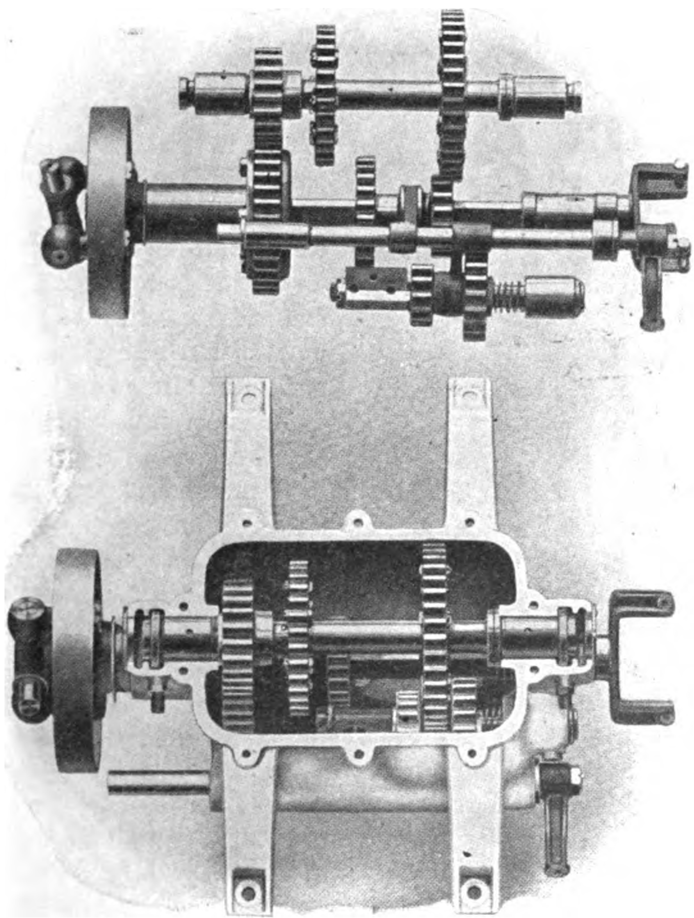


Fig. 28. Sliding Gear Transmission.

of engagement by which the operator can cause the single shifting lever to engage any desired fork, and thus put into operation any gear which is brought out of operation as the lever passes to neutral, where it is again ready to engage any desired gear.

The objections made to the sliding gear device is that this method of meshing gears is unmechanical, wears the gears rapidly, is likely to break them, and the means of shifting is much slower and therefore less safe and handy than the individual clutch or the planetary systems. It is argued, for example, that in the sliding gear the operator must withdraw the clutch, then withdraw the gear, then shift the gear lever, then cause it to engage a different gear and finally complete the operation by letting in the clutch–a total of five movements. In the planetary device the same motion that withdraws the high clutch will, if continued beyond the neutral point, engage the low one and vice versa, while in the individual clutch system one movement disengages the clutch and another, usually of the same lever, engages another clutch, with its corresponding gears; at most two movements, and in many forms accomplished by a single movement.

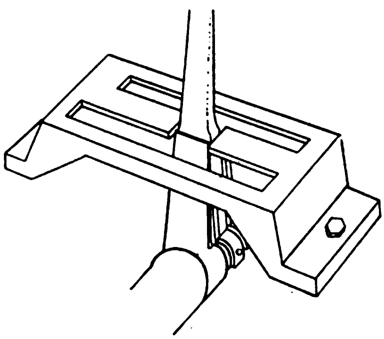


Fig. 29. Single Lever Quadrant, Selective Type.

The importance of quick action in a crowded street or on a steep hill can hardly be overestimated, particularly since motor vehicles are rapidly-moving devices and but little time can be allowed for the performance of any simple function like speed changing. In spite of this disadvantage, however, the sliding gear seems to be increasing in popularity, which is probably due to the fact that many people regard the foreign vehicles as superior to the American, and the sliding gear is a foreign device. It seems also probable that the greater simplicity of the sliding gear system as compared with the individual clutch has caused it to find favor with the makers, to whom simplicity means cheapness, and who are not so much concerned as to whether or not it is most easy to operate. The simple device is not only cheapest for the manufacturer but it is generally more easily understood and maintained by the owner, and should, if other things are reasonably near equal, be given preference.

Friction Gear. The friction gear, although but little used, is an exceedingly old form. It was probably the first form in the thought of

every designer in connection with the gas engine, for in the early days gas engines were regarded as being inflexible, and a flexible driving gear was considered an absolute necessity. Lack of positiveness, the objectionable pressure necessary to secure driving friction, the disturbing effect of grease, frost or water when found upon the friction surfaces, the large size of the discs required, and the constant loss of power due to the fact that variable friction devices cannot be constructed upon rolling cone lines, all conspire to make friction devices objects of suspicion to which most designers were unwilling to confine their efforts. Successful use for many years upon vehicles of even the heaviest weights has proved that friction driving gears are capable of successful use and excellent service, and that their advantages and objections compare favorably with other systems.

Several forms have been used, of which the most common form, and the one longest in use, consists of a disc on the engine shaft parallel to the plane of the fly-wheel and often formed by the fly-wheel itself. Parallel to this disc is a driven shaft on which the driven disc is arranged to slide with its edge in contact with the face of the driving disc. This driven disc can be shifted from the extreme outer edge of the driving disc, which is usually high speed position, to a position which is beyond the center of the driving disc, which is a reverse position. At the center the driving effect is nothing and the driven disc would stand still but is usually disengaged at this point. This form has been in use for five years on Union vehicles and has been thoroughly tested under every condition of road service.

A modification employs two additional discs, one journaled on the cross shaft with its edge engaging the reverse surface of the driving disc, the other journaled independently on a short shaft in line with the driving shaft and with its outer surface engaging the edge of its mate, while the driven disc engages its face opposite the point of engagement on the driving disc. This arrangement applies power to the driven disc at opposite sides, which balances the pressure and increases the driving effect to a considerable extent.

A modification of these forms reverses the positions of the discs and employs the shifting disc as the driving device with its edge moving across the surface of the driven disc. This reversal secures great power at low speeds, but for pleasure motor vehicles this is not so desirable, for they are usually driven on the high gear, depending upon

the throttling of the engine for necessary variations in speed, and friction discs of this arrangement are quite wasteful of power when the transmission point is near the center of the disc surface. This is because of the fact that the point of contact is not actually a point, but covers a considerable surface, on which account a considerable slip and loss of power results. This slip is dependent both upon the width of the friction edge in contact with the disc and upon the curvature of that circle of the disc in contact at any particular time.

If we assume the contact surface to be more or less elliptical in shape, it will readily be seen that the surface must necessarily slip in

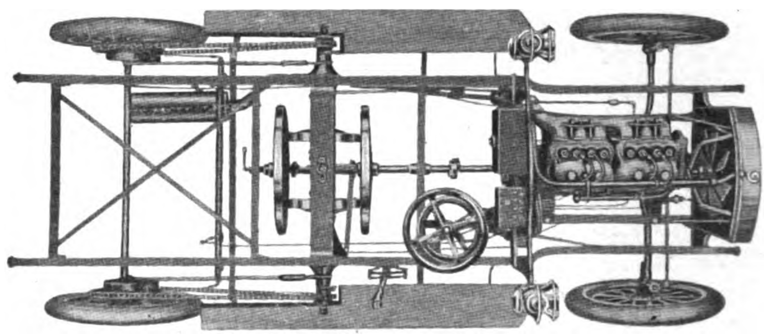


Fig. 30. Windsor Friction Drive.

opposite directions on opposite sides of the center of the contact area, and that this slipping is both across and with the edge of the driven disc.

A third form of friction in use on the Windsor vehicle is a modification of the second form. In this the driving shaft is equipped with two discs between which is placed two halves of a cross-shaft, each equipped with two edge-driven discs. These half shafts are so mounted that their adjacent ends can be thrown in opposite directions and the discs on them are likewise mounted to move oppositely and in like proportion. Since the driven discs are on opposite ends of the driving shaft, it is obvious that if one is thrown forward and the other backward, both will be rotated in the same direction, whereas if they are thrown in the opposite direction a reverse motion will be given. This obviates passing the center of the driving disc to secure a reverse, and since it is seldom or never necessary to have an extremely slow speed, the driven discs need not be shifted greatly to produce the

variations in speed, which is done by shifting them toward or from the other edges of the driving discs. The illustration makes the arrangement plain without further explanation. The amount of clearance is so slight that the movement of the half shafts out of a direct line is too little to have any practical effect of a detrimental character.

A fourth form is arranged to make use of the friction drive only for such variations in speed as are necessary below direct drive, and

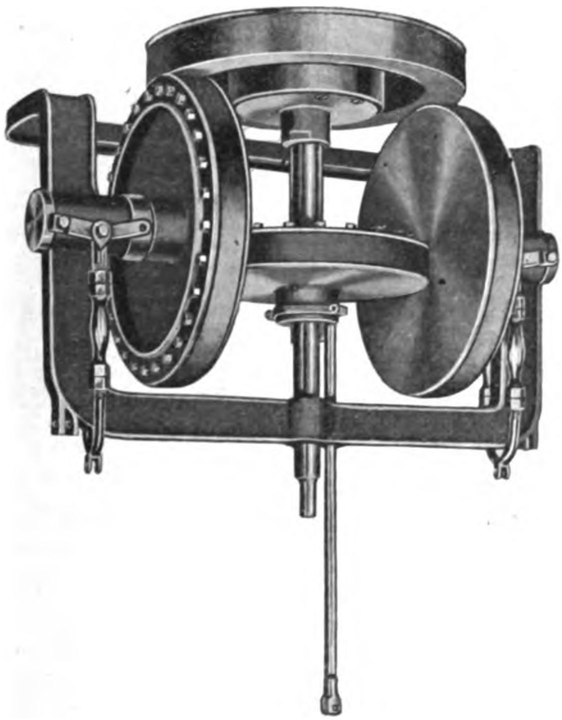


Fig. 31. Friction Drive for Variations in Speed below Direct Drive.

secures the advantage of direct drive without loss for high speed work. This arrangement seems particularly adapted to pleasure vehicle service and will doubtless find large adoption in future. In this construction the driven disc stands parallel to the fly-wheel and is shiftable toward and from the fly-wheel surface. The edge of the driven disc engages the plane surfaces of two or more intermediate discs, journaled on short shafts parallel to the plane of the fly-wheel. The edges of these intermediates engage the fly-wheel by gear or friction as may be,

and transmit power to opposite sides of the driven disc. Shifting from the center of the intermediates toward the fly-wheel increases the speed, while in the opposite direction beyond the center gives the reverse. When near the fly-wheel a clutch is engaged, which connects the fly-wheel and driven disc positively after which the intermediates are disengaged, leaving direct drive on the high gear.

VEHICLE CONTROL

With all these devices the operator is called upon to perform certain operations, such as setting and releasing clutches, shifting the discs in and out of contact, or shifting and selecting the gears to be used. In the operation of the vehicle, he must have in mind the important function of speed changing, in addition to the equally important ones of steering and throttling the motor, together with minor functions such as spark management, lubricator oversight, and tooting the horn or sounding a gong, which is frequently required by law. Such a multiplicity of duties is confusing to many operators accustomed only to drive a gentle horse, which requires but guiding and speed regulation, and there is no doubt but that many accidents are due to the operator in an emergency becoming confused and failing to do the right thing to prevent trouble.

It is, therefore, quite necessary that vehicle control should be as simple as possible, and while some designers have eliminated minor details, such as spark control, and the necessity for watching the oil or water circulation, and have reduced the operation of the vehicle to steering and throttling, with sufficient power to drive a large and flexible engine almost wholly on the high gear, and without speed changing, others have eliminated speed changing entirely by making it automatic. Thus in the Sturtevant machines, the fly-wheel is provided with two or more sets of governor weights. When the engine is throttled extremely low, these weights are all drawn in by springs and all drives are disconnected, leaving the vehicle standing still. If the motor is speeded up, the lightest set of springs permit one set of weights to throw into engagement the low speed gears, and these continue in engagement until the vehicle attains considerable speed, when a second set of weights throw out, bringing into action a higher gear, which drives the vehicle at a higher speed. The lower speed gears

become inoperative because of a ratchet provision which permits over-running the low gears, whenever the driven part acquires a speed above that imparted by the low gears. If the speed decreases, the high speed weights are drawn in by their springs and the low gears take up the work, until, as when stopping, they too become inactive because of lack of speed. This arrangement eliminates speed changing entirely and renders the vehicle more suited to the use of every member of the family than are most vehicles—a condition that sooner or later must come to pass.

Combination. In a few vehicles the motor has been used direct connected to a dynamo to generate electricity, which, either through a storage battery, or direct to a motor, is used to produce the necessary speeds. This system has not been largely applied to pleasure vehicles, but has seemed best adapted to commercial vehicles where, because of widely varying loads, widely varying powers are needed, and the electric motor not only provides a steady application of power, but in connection with the storage battery, is capable of great exertion for short spaces of time, and undoubtedly does give an almost ideal method of speed changing. The added cost and weight of a double system of this kind is quite likely the chief argument against it.

It has also been proposed to use pumps for water or oil directly attached to the engine, while a motor adapted to be driven by liquid was directly connected to the rear axle. Such a device, while doubtless flexible and smooth running, is admittedly inefficient and not easily maintained in proper working condition.

CLUTCHES

Since the gas engine must be started from an outside source, and runs with but little power when cold, it is practically necessary to have a clutch by which the engine can be disconnected from the driving gear or at least from the propelling wheels. The forms of these clutches are quite varied. In connection with the sliding-gear change-speed device the clutch is usually placed between the fly-wheel and the change-gear box and is generally of the conical variety, one member forming part of the fly-wheel and the other being attached to the shaft entering the gear box. One surface is usually faced with leather or similar material having a high friction coefficient, and a

strong spring is arranged to hold the members in engagement. A pedal like a brake pedal is usually provided to withdraw the driven member, with a ratchet for holding it withdrawn while the motor is being started.

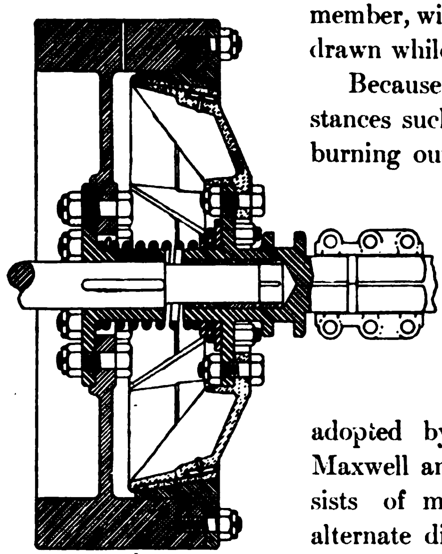


Fig. 32. Conical Clutch.

Because of the rapid wear of soft substances such as leather, and the danger of burning out the clutch surface in a few minutes after a clutch begins to slip, as well as because of the objectionable size necessary to secure an effective clutch of this kind, a better form of clutch has been recently adopted by leading makers, such as the Maxwell and Stevens-Duryea. This consists of multiple discs of metal, each alternate disc being attached at its edge to the driving member and the other discs attached at their centers to the driven member or vice versa. Light springs cause these to separate sufficiently to be clear of engagement when the clutch is released. The total amount of surface is so large that the friction coefficient may be very small. This form of clutch generally runs in oil, has no appreciable wear, needs no adjustment and the very worst that can happen is to burn out the oil between the discs and thus greatly increase their friction coefficients.

Fig. 33. Pedal and Ratchet.

A very common form of clutch consists simply of a band, frequently lined with leather, vulcanized fiber, or even canvas, which is provided with means for causing it to grip the surface to be held. This form is commonly used in connection with planetary gears and is much employed as a brake device.

In another form of clutch the surface to be gripped is not on the outside, as with the band, but is an inner circumferential surface, and two or more shoes or short segmental sections are caused to press

against this inner surface by toggles operated by a collar shifted lengthwise the shaft. This is one of the earliest forms of individual clutches, and was used by Fawcett in an omnibus driven by an internal combustion engine at Pittsburg in 1876. A great variety of modifications of the devices just described are to be seen in use to-day, but with a knowledge of these most important forms the modifications are easily understood upon inspection. Square-jaw or positive clutches are used in some instances, as in the White steamer or the Chicago friction drive, and serve to change the speeds. Such clutches are used in some change gears instead of sliding the gears.

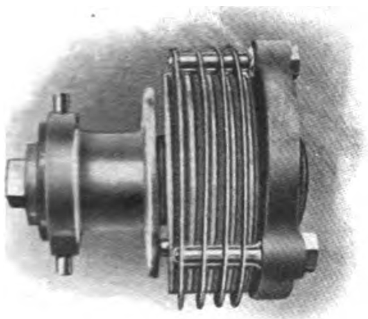


Fig. 34. Multiple Disc Clutch.

TRANSMISSION

After passing the change-speed gear, the power is transmitted usually to the balance gear, and for this purpose the single chain is the most common form. This is so simple as to need but little description, being known in its simplest and most successful form on practically all bicycles. The front or driving sprocket is usually small, the larger or driven sprocket being several (three or four) times the diameter of the front.

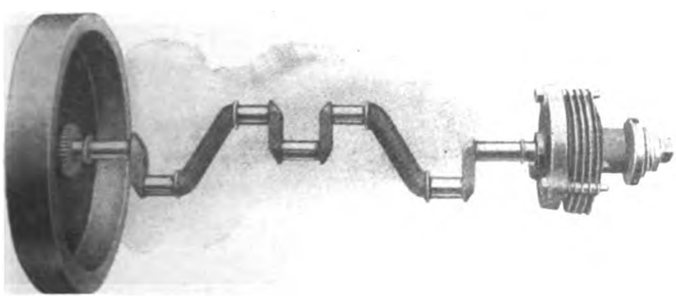


Fig. 35. Stevens-Duryea Fly Wheel, Crank Shaft and Disc Clutch.

The block chain adopted from bicycle service was the first form used on American motor vehicles, but being of bicycle size in almost every instance, was found totally inadequate and was therefore almost universally condemned. Not only the chain but the sprockets were too small, with the result that both wore out quickly and breakages

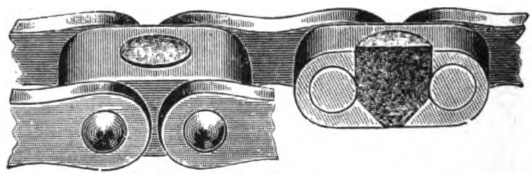


Fig. 36. Duryea Chain with Felt Lubricator.

were frequent. The block chain has less parts than the roller, has less joints to gather grit, is less noisy and, if of proper strength and properly fitted to the sprocket, runs with as little friction and transmits power with as great efficiency as any device yet offered. Few block chains are in use to-day, but of the few, the Duryea is noticeable because the blocks are bored transversely, so as to just intersect the rivet holes, and this transverse bore is filled with a felt pad, which absorbs oil and keeps the rivets properly lubricated. The value of oil upon any bearing is self-evident, and this arrangement not only insures oil in the proper place, but permits the outer surfaces of the chain being kept clean and practically free from grit, so that the rivets are not likely to wear in their bearings, nor do the teeth of the sprockets wear so rapidly as usual.

The roller chain is the most common form and is so called because each rivet passes through a bushing around which bushing a roller is placed, so that the chain pull is taken by the roller bearing against the bushing, while the rivet is journaled inside the bushing. The reason for this is that as the chain lies down in its place upon the face of the wheel, the roller rolls down the teeth instead of sliding, but this reason is based upon chain imperfections and is not a proper one in connection with good chains and properly cut sprockets. If the chain and sprocket fit

Fig. 37. Roller Chain.

properly, the pitch of the chain is slightly less than that of the sprocket, so that the rollers or blocks rise and fall out of and into their places, as the sprocket revolves, without friction. If, however, the chain is over-pitch, it will be loose at the middle of its length of contact on the sprocket and will grind and bind where it comes in contact and where it leaves the sprocket, and while rollers may partly overcome this grinding, the loss of power in any event, is decidedly objectionable, and such chains should not be continued in use.

It is to overcome this defect in driving chains that self-adjusting chains, like the Renold silent and the Morse silent chain, have been put upon the market. These have not come largely into use on autos because of their high first cost, but they are undoubtedly most meritorious, as they wear as long as gears, are more flexible, are less noisy,

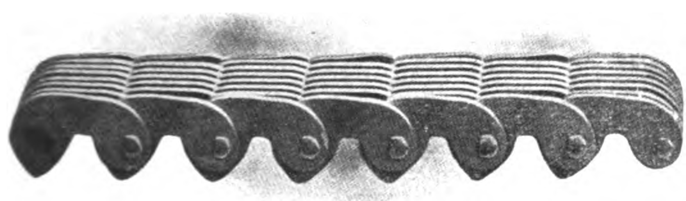


Fig. 38. Morse Silent Chain.

transmit as much power for a given width of tooth and need no more attention than gears. Their decided advantage is in the shape of the link, which causes the chain to select its own pitch line on the sprocket. Because of this feature they do not stretch and get out of pitch as do chains of ordinary construction, but any stretch of the chain, due to the wearing of the pivots, is compensated for by the fact that the chain automatically takes a larger pitch line position on the sprocket, whereas in chains of the usual kind an increase of pitch causes the chain to grind and rapidly wear the tooth surfaces, as the chain takes its position on the sprocket with much loss of power and with an increasingly rapid destruction of both sprocket teeth and chain.

The pitch of a chain is the distance from center to center of similar rivets, having one chain link between them. In roller and the silent chains mentioned, it is the distance between rivets. In block chains each link is composed of one block and two side pieces, which are held

together by a rivet, so that the pitch of the chain is the total of two spaces adjoining. This pitch distance is measured in a straight line forming one side of a polygon having as many sides as the sprocket has teeth, and corresponds to the older and now less used circular pitch as applied to spur gears. In circular pitch the gears were measured from center to center of tooth, just as sprockets are measured, these measurements being taken on the pitch line. In the later and more common method of measuring gears, the pitch is expressed by the diameter of the gear at the pitch line. Thus, an eight-pitch gear has eight teeth on its circumference for each inch of diameter. The pitch line of a gear is about midway of the tooth and is the line common to both gears; similarly the pitch line of the sprocket and chain is the line of the rivet centers as the chain lies upon the sprocket.

Although less applicable to belting, the pitch line of a belt is approximately at its center and should be taken into consideration when considering pulleys for belt driving.

In some vehicles more than one chain is used, either from the motor shaft to the counter shaft, as in the Holsman,—which employs chains for its change-speed device—or as in many forms of large vehicles which employ two chains from a counter shaft to the rear wheels. The counter shaft is parallel to the rear axle but in front of it, and is fitted with a sprocket on each end, in line with the large sprocket on the corresponding rear wheel. This construction is usually applied to heavy vehicles, and in this construction the balance gear is in the counter shaft and power is frequently transmitted from the change-speed gear to the balance gear by propeller shaft.

Chain troubles usually consist of broken links or sheared rivets, due quite frequently to something getting between the chain and sprocket and thus subjecting the chain to undue strain. If the chain is quite loose, it may climb on top the sprocket teeth with the same result. As the chain wears and increases its pitch length, the tendency to climb the teeth is increased and it will run with a grinding noise, indicating rapid wear. A block chain can usually be reversed with good results after it is partly worn. Extra links are usually carried for repair purposes, and some chains have their rivets buttonholed into the side links, while in others the rivets are held by cotter pins, so as to permit quick repairs to be made.

Chains have been condemned because they have been abused, whereas if properly designed, cased, and cared for, as is necessary with gears, they will give as good or better service.

The propeller-shaft transmitting device is so named because of its resemblance to the shaft used to transmit power from the motor to the screw propeller in boat service. At its forward end it is driven by the motor or change-speed gear just as in a launch, while at the rear end it is fitted with bevel gear usually of small diameter, meshing into a larger bevel gear on the rear axle or counter shaft at right angles

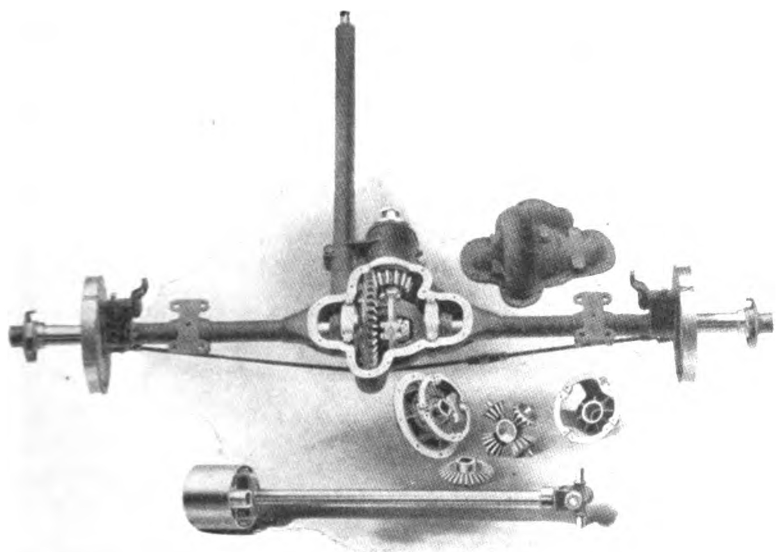


Fig. 39. Propeller Shaft Transmitting Device.

to the propeller shaft. In some cases a worm gear is used instead of the bevel, while in others equivalents having pins and rollers instead of teeth are employed, the aim being to reduce the friction of the bevel gear. The bevel gears are commonly encased to hold oil and keep out the dirt, and this casing contributes very largely to the good service given by such gears. In all bevel gears there is a decided thrust against the bearings, which must be strongly resisted if the gears are not to become separated at their pitch line, causing increased noise and friction.

Gimbal Joints. Because of the impossibility of holding the motor at the front of the propeller shaft and the gears at the rear in alignment with each other, it is common to provide the propeller shaft with knuckles or gimbal joints, which, while transmitting power perfectly, permit the shaft to yield and change its direction ten or even twenty degrees. The propeller shaft is usually provided with a telescopic joint which permits it also to vary in length between ends, and these two accommodations allow the springs of the vehicle to perform their function without interfering with the transmission of the power. A great variety of gimbal joints have been employed and the same is true of the telescopic joint. These joints are frequently encased in leather cases packed with hard grease, which both keeps out the dust and insures lubrication.

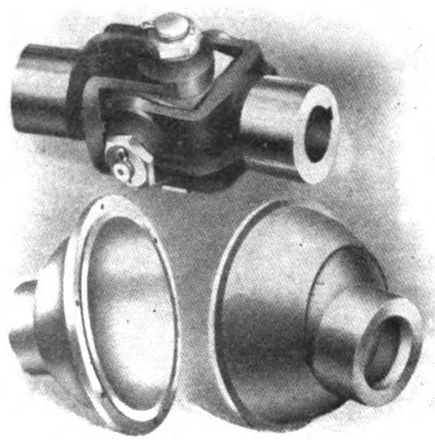


Fig. 40. Gimbal Joint.

Radius Rods. The propeller shaft is frequently paralleled by a torsion rod or bar having sufficient stiffness to resist the push of the bevel gear as it transmits the driving effort to the axle. In any event, this strain must be resisted by some means, and in connection with chains it is manifested as a forward pull parallel to the chain, which is taken by distance or radius rods arranged to extend from the driven axle to, or nearly to, the driving one. In some faulty con-

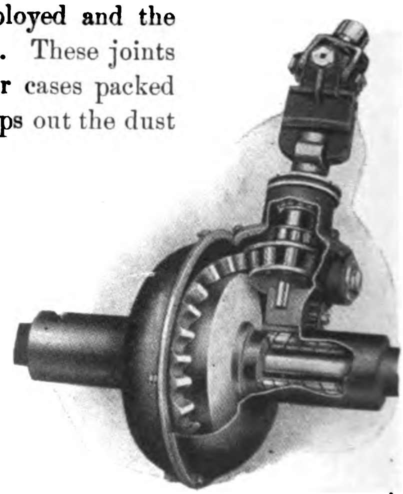


Fig. 41. Roller Bevel Gears and Universal Joint.

structions the distance rods are attached at one end or the other some distance away from the axle centers with the result that the spring action gives rise to a travel of the axle not coincident with an arc drawn around one axle center and passing through the other, and the result of this lack of proper movement is either to loosen the chain or tighten it, resulting frequently in the chain running off or being strained so forcibly as to break it.

Balance Gear. The balance gear, frequently called differential, or jack-in-the-box, is a device intended usually to transmit the power from the sprocket or bevel gear to each half of the countershaft or rear axle and thus to each wheel equally at all times, regardless of whether the wheels are turning at equal speed on a parallel course, or one slower than the other, as in turning a corner. In its simplest form it consists of two large bevel gears attached one to each half of the rear axle, which carries at its outer ends the driving wheels, or in the case of the countershaft, the sprockets for the side chain. Between these large bevel gears is journaled the driven sprocket or driven gear, the hubs of the bevel gears sometimes forming the journals. In this sprocket or gear are one or more pinions, usually three or four mounted substantially upon spokes and arranged to mesh into the large bevel gears of the balance gear.

In theory each of these pinions is simply a lever receiving the pull of the chain at its center and because its ends (opposite teeth of the pinion) engage the opposite bevels, it transmits half of the pull received to each of the bevels. When the vehicle runs on a straight course the pinions and bevels revolve as a solid mass without relative motion, but if, as in turning a corner, one bevel and its corresponding rear wheel takes a slower motion, that end of the lever (pinion tooth) is retarded, while the opposite end of the lever (pinion tooth) moves forward more rapidly, driving the outer wheel of the vehicle with increased speed. In all cases the amount of force applied to each wheel is the same, since both ends of the lever are of equal length, the only variation being a slight loss by friction, due to the motion of the parts of the gear in relation to each other. While the bevel gear is the simplest form, many balance gears are constructed by the use of spur gears because spur gears are manufactured more cheaply. In this form each half-axle

is fitted with a spur gear, while the sprocket is provided with studs or bearings parallel to the axle on which are journaled long spur pinions, usually of small diameter. At their inner ends, these pinions mesh into each other, but one projects to one side of the sprocket, the other to the other side, and these projecting ends mesh into the spur gears. The power transmitted to the sprocket is, by the teeth of these pinions, transmitted equally to the spur

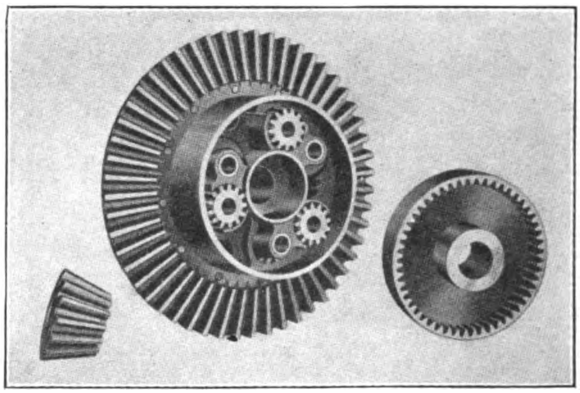
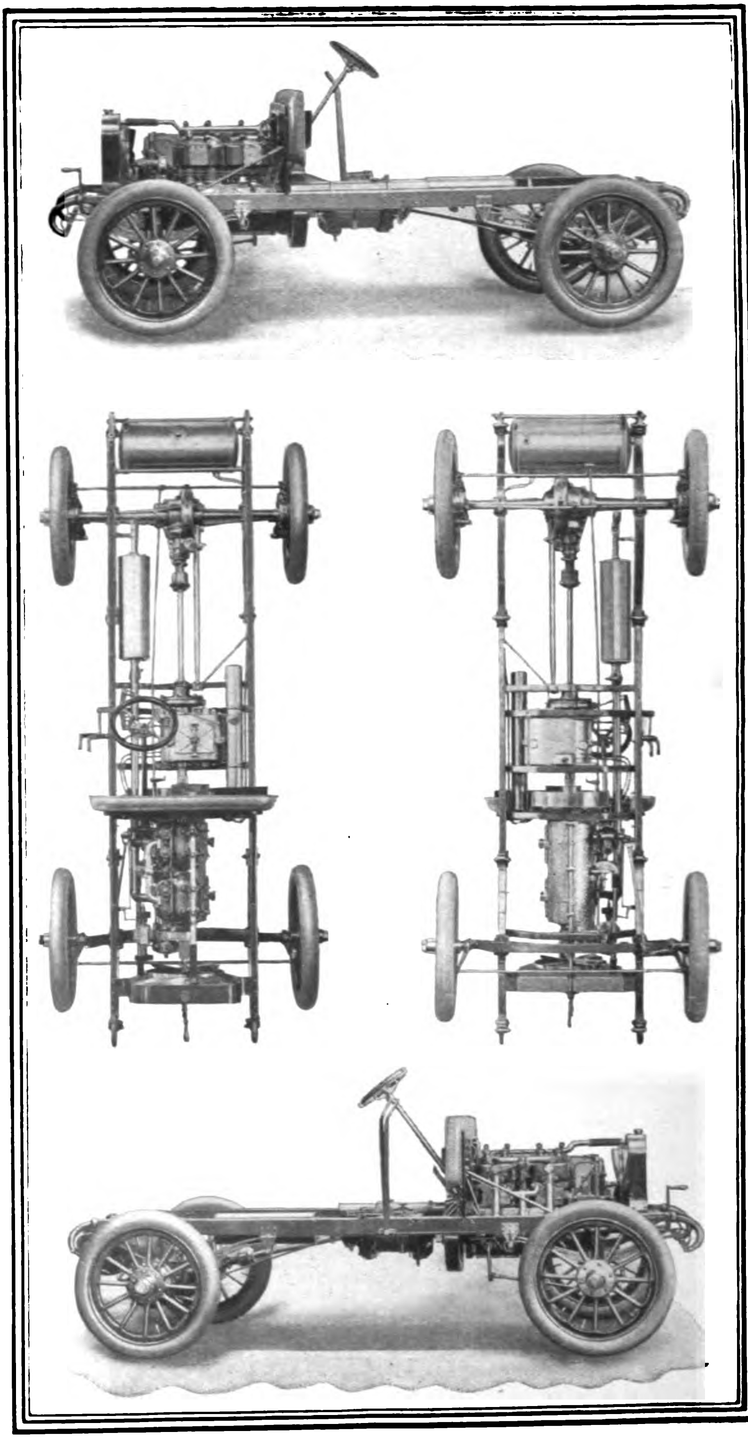


Fig. 42. Spur and Internal Balance Gear.

gears in which they mesh, while variations in speed are met by the rotation of the pinions in opposite direction, which accomplishes the same result as the rotation of the bevel pinion.

A third form of this device now little used, employed a spur gear on one half axle, an internal gear of larger diameter on the other half, with a single spur pinion meshing into both and mounted on a stud projecting from the sprocket. The pull of the sprocket was transmitted by this stud and pinion equally to the large internal gear and the small spur pinion, but since the point of application or pitch line of the internal gear was farther from the axle center than the pitch line of the spur gear, the effect was to drive the one wheel more strongly than the other. This arrangement is particularly advantageous where the resistance to be overcome is greater on one side of the vehicle than on the other, as for example in the three wheeler having the third wheel arranged to track with one of the drivers, for it differentiates or transmits the



GROUP OF MODEL K CHASSIS
The Winton Motor Carriage Co.

power in different proportion, whereas the usual form being balanced, is really a balance gear.

Other devices are in use to transmit power to both wheels, as is necessary to secure traction and a forward movement without a tendency to shift to one side, and most of these aim to avoid the balance gear. The objection to the balance gear aside from its cost and weight is principally that if one wheel strikes a slippery spot, as a piece of ice, and slips backward, no power is transmitted to the other wheel and propulsion ceases. This is because the slipping wheel moves at double the angular velocity of the sprocket instead of at the same velocity as would be the case if both wheels were revolving at the same rate of speed.

In one or more types of friction-drive vehicles two driving discs are used and no balance gear is employed, it having been found that the friction discs will slip sufficiently to permit satisfactory turning, while on the other hand, if one vehicle wheel slips, the driving ability of the other is in no wise lessened. In the rope-driven Holsman, and one or more of its type, the slip of the driving ropes is utilized in a similar manner. The Hedgeland solid axle not only does away with the loss of strength or the increase of weight, due to the use of half axles, but it secures a positive drive to the slow wheel and thus avoids loss of traction by the slipping of one wheel. In this device each end of the axle is provided with a clutch fitted to the wheel hub so as to remain free when the wheel moves faster than the axle or when the axle stands still with reference to the frame of the vehicle. A forward movement of the axle causes the clutch to grip the wheel and drive it forward, but at all times

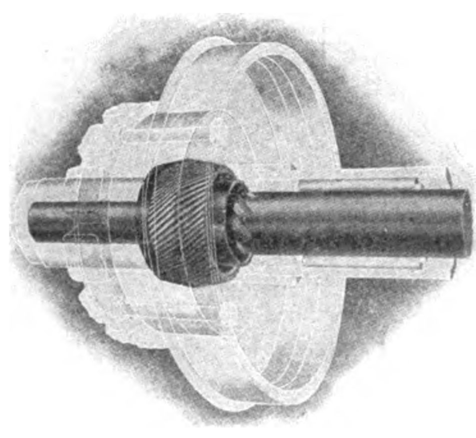


Fig. 43. Hedgeland Solid Axle.

the wheel is free to turn with greater angular velocity than the axle and thus releases itself.

In reversing, the same action results in the opposite face of the clutch being brought into service, while in coasting the vehicle runs free without the necessity of turning the rear axle and propelling mechanism.

Rear Axle. Directly connected with the balance gear is the design and construction of the rear axle. A quite common form consists of two half axles passing through the tubular half frames, which are bolted together around the balance gear forming the balance gear box, frame or spider. Each half axle is a duplicate of the other as is each half of the rear framework, and each is

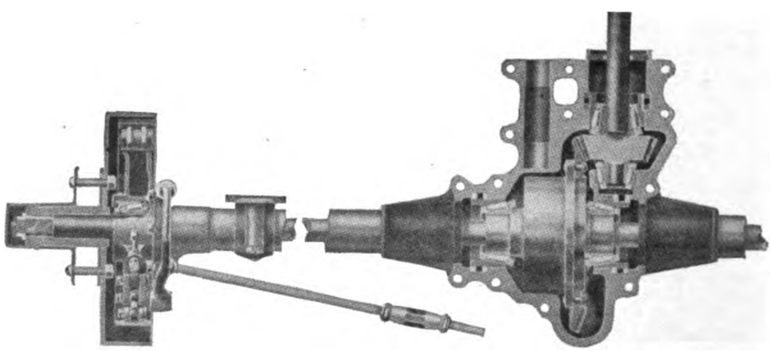


Fig. 44. Rear Vertical and Horizontal Views of Shaft-Driven Rear Axle.

provided with bearings at the inner end near the balance gear and at the outer end adjoining the vehicle wheels. In some construction the balance gear is not exactly at the center but is at one side, making one of the rear axle parts and the tubular portion of its case shorter, while the opposite parts are correspondingly longer.

A second form of axle employs a full length axle, having fixed, generally near one end, one of the balance gears, while slipped over this end, is a sleeve, carrying the other balance gear. The outer end of the sleeve on one side and the outer end of the axle on the other are fitted to the corresponding vehicle wheels. A nut on the sleeve end of the axle holds the sleeve in position, and sometimes also holds the wheel in place, the whole forming a simple and satisfactory construction. Both of these forms are

what is known as "live axles," *i. e.*, axles which revolve with the wheels. They are advantageous in that the use of a single sprocket is permitted, and this may be placed in under the vehicle, thus bringing the chain away from the dirt of the wheels, where it is less unsightly and more durable. The disadvantage of the live axle is that it must be quite strong to properly carry a given load, because in revolving it is subjected to stresses in opposite directions, and is therefore likely to be broken.

Dead axles are commonly used on heavy vehicles, and these are substantially the same as on horse vehicles. With this construction each driving wheel is fitted with a sprocket from which a chain runs, usually forward, to the projecting end of the countershaft. The balance gear and axle constructions heretofore described, apply, with slight modifications, to the countershafts, which, because of the gear reduction between the countershaft and the rear wheels, need differ only in that they are not so strong and heavy.

Front Axle. The front axle of a motor vehicle differs usually from horse vehicle construction in that there is no fifth wheel at the center of the axle about which the axle turns for steering pur-

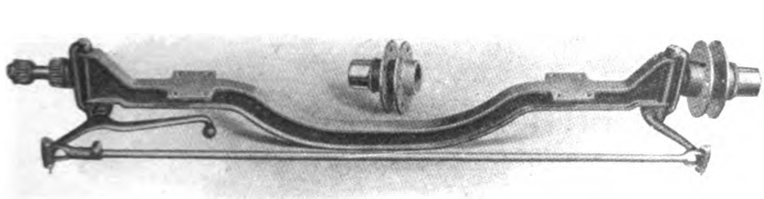


Fig. 45. Complete Front Axle Showing Steering Heads and Tie-Bar.

poses, although this construction is sometimes used; but generally each end of the axle is provided with a steering head into which a vertical spindle or neck is journaled, which neck carries the axis of the corresponding front wheel. To this neck is attached one or more steering arms for controlling the direction of the neck; and that the opposite wheels may be steered in unison, an arm on one side is connected with a corresponding arm on the opposite side by a tie-bar parallel to the front axle.

It is readily seen that in turning a corner both front wheels should be so turned that each will describe an arc concentric with the arc of the other, for if both arcs are not concentric, one wheel or other will be forced to slip sidewise to a greater or less extent, with the result that the tires will be worn and the steering will sometimes be controlled by one and sometimes by the other wheel, with consequent greater skidding and a very disconcerting eccentricity in the matter of steering. The same result is found in driving straight ahead if the steering wheels are not parallel to each other as they should be.

To insure that the steering wheels describe concentric arcs, the steering arms are projected either backward and inward from the steering neck or forward and outward, and the tie-bar is made of suitable length to hold the wheels parallel for straight ahead driving. This arrangement insures that the inner wheel on a turn will be steered at a greater angle from the center line of the vehicle than the outer wheel, and will describe an arc of a circle of shorter radius than the outer wheel. It is quite evident that both wheels should steer around a common center and that the radius for one wheel in one case must be the width of the vehicle, usually about 5 feet, greater than for the other wheel. The proper angle for these steering arms depends upon the distance between the axles and the distance between the steering head center lines, and is found approximately by drawing a line through the steering head center to the middle of the rear axle.

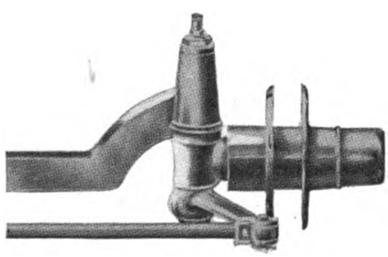


Fig. 46. Front Axle with Lemoine or L Head.

Steering Heads. Steering heads are of several varieties according to the ideas of the designer. The simplest form is an L-shaped forging welded to the end of the straight front axle, the other member of the L projecting upward or downward, and in either event bored to receive the steering spindle. This is quite frequently termed the Lemoine type. A second form provides the axle with a T head, the extremities of the T being turned at right

angles, so as to form lugs through which the steering pivot pin passes. This also passes through the steering neck fitted between the lugs. This form is commonly termed the Elliott type. Recognizing the advantage of having the steering pivot as close to the spokes as possible, several makers made these projecting lugs very long, and in place of the vertical neck a curved C-shaped neck was provided carrying the spindle at its center, while at its ends short pivots or screws attached it to the lugs mentioned. This arrangement permits the use of a long wheel spindle and although slightly more expensive to build, and not quite so rigid as the other types, was used because of its merit by Haynes for a number of years.

In any steering device, the object is to have the steering pivot close to the wheel, so that the leverage of the wheel is extremely small, on which account obstacles do not have much tendency to deflect the course of the wheel. Any one who has watched the long pole of a horse wagon sway violently as the front wheels strike an obstacle, can realize how impossible it would be to control a motor vehicle by the arm of an operator unless a considerable mechanical advantage is gained in some manner, and placing the steering centers nearly or quite in the plane of the wheel, secures this advantage to a more or less complete extent.

Some vehicles are equipped with hubs of such size that the steering pivot may be placed exactly in the plane of the wheel, the wheel bearings being of larger diameter than the length of the steering pivot. Other vehicles use forks astride the wheel with the steering pivot over the wheel as in cycle construction. Both of these methods remove all leverage from the wheel, so that there is no tendency to deflect to one side or the other when it strikes an obstacle; but the large hub is objectionable and the long fork with the long framework necessary to get above the wheel is both costly and weak. The advantages of these constructions can practically be secured without additional cost or disadvantage by inclining the steering pivot so that the steering pivot center line strikes the ground at the same point as does the wheel. This construction is used on a number of vehicles at present and its merits will eventually force it to be used by all.

A few vehicles have been steered by the single kingbolt and fifth-wheel arrangement used on horse vehicles, in connection with a worm and segment for turning the axle about this pivot. This form is common in vehicles which both drive and steer by the front wheels, and is quite practical if means for steering by the power of the motor is provided. In order that the worm may have the power required it is of slow pitch and needs many revolutions to effect the desired steering, which rapid movement is not easily made by the operator. A device is easily provided, however, so that the motion of the motor drives the worm in either direction at will and accomplishes the desired result.

A double form mounts both front and rear axles on fifth wheels and swings them in opposite directions, thus steering both ends of the vehicle.

Front axles are usually solid, although sometimes made tubular for the purpose of saving weight. A single tie-bar between the steering arms is commonly used, but for the purposes of safety double ones are sometimes provided.

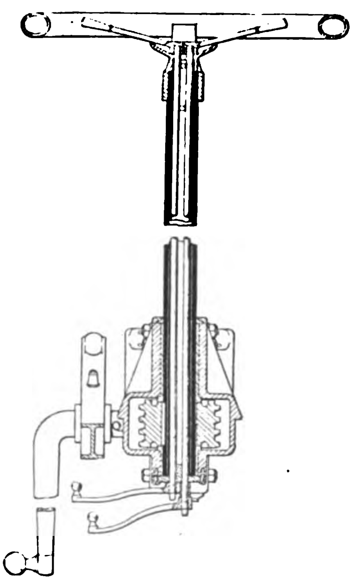


Fig. 47. Steering Wheel.

Control. In order that the front wheels may be controlled by the operator a number of means are used, the most common of which is known as wheel steering. This consists of a rotatable post fitted with a wheel at its top end and with a crank, pinion, or worm at its lower end. Where the crank is used a connecting rod connects the outer end of the crank with one of the steering arms which project from the steering head. Turning the wheel to one side a quarter turn throws the steering wheels to their limit in one direction from the center position, and a similar opposite turn throws them in the opposite direction. As commonly arranged, the post is turned in the

same direction as are the steering necks, so that the rear of the steering wheel moves in the same direction as the rear of the front wheels of the vehicle. In the earlier forms the steering post was vertical, but it is now considered advisable to incline the post backward at the top so that the operator's seat need not be so nearly over the front axle. The front end of many vehicles is

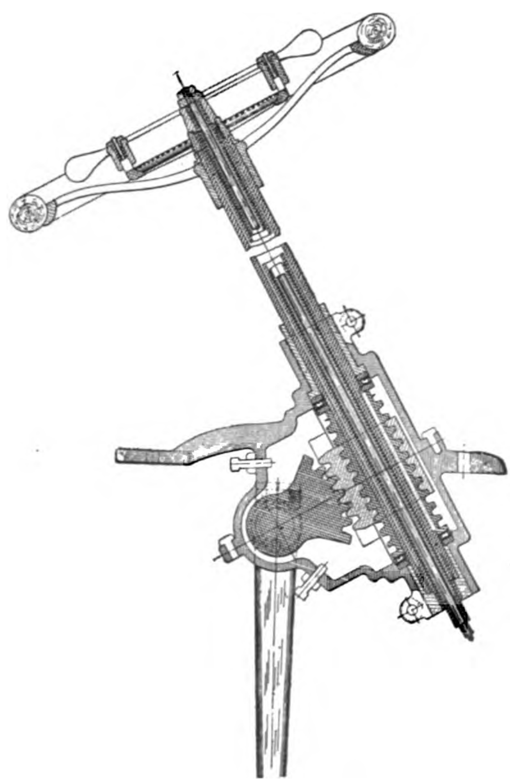


Fig. 48. Steering Wheel Showing Throttle and Spark Levers.

now utilized for the motor and as the wheels are steered, the front of the vehicle moves to one side or the other in a manner not found in horse vehicles and not conducive to comfortable riding. This objectionable feature is not found farther back, on which account the passengers are usually carried nearer to the rear axle. In some vehicles, the vertical post is equipped with a tiller or rearwardly projecting lever. This was formerly much

used on light vehicles and is a simple, natural method of steering, but not so satisfactory as other methods.

In other instances, the vertical post stands at the center of the operator's seat or at one side thereof, while the steering lever projects across the vehicle in front of the operator. This gives a powerful method of steering and is preferred by many to the tiller steering.

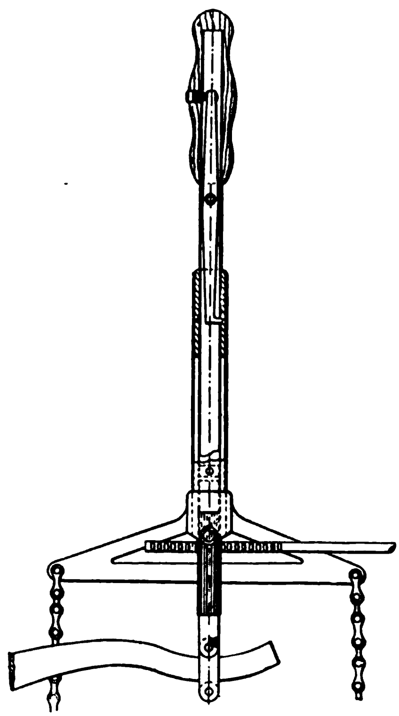


Fig. 49. Duryea Controlling Lever.

Swinging the lever sidewise pulls the chains and steers the wheel. Sliding the handle up or down shifts the lever setting either the high or low clutch. Twisting the handle shifts the rack which controls the throttle.

In order to get still greater power, double levers or handle bars have been used, but the preferred method is the wheel operated by both hands in connection with the worm or pinion at the bottom, by which arrangement the rotation of the post is not confined to a half revolution but is usually arranged to make nearly two revolutions and in some cases more, in order to turn the steering wheels through their extreme movement. It will be understood that the pinion meshes into a sliding rack attached to the proper end of the connecting rod, and that the amount of movement of the front wheels depends upon the diameter of the pinion.

When a worm is used the arrangement is slightly more complex, there being usually a segment of a gear adapted to mesh into the worm, so that a quarter revolution around the center of the gear is produced by the two or more turns of the steering post. Attached to this segment, is an arm connected usually by ball and socket joint to the connecting rod. The advantage of this construction is that the worm locks the front wheels of the vehicle in position, against deflection

by obstacles or causes other than the will of the operator. This arrangement is known as lock steering and is preferred by some. The free steering is the more common form, however.

A further form of steering employs a vertical lever carried by a horizontal pivot at the center of the seat near the front, and arranged to swing sidewise for steering purposes. This lever is between the passengers, does not interfere with mounting or dismounting, is in position to be operated by either passenger, and is much liked by those who have used it as well as other methods. Being patented, it is employed on one make of vehicles only.

Brakes. Second only to ability to go is the power to stop, on which account the brakes are most important. A wide variety of these have been used in the past but practically all have been abandoned excepting band brakes. A tire brake consisting of a shoe bearing against the tire of the wheel is considered detrimental to the tires and does not hold well on wet rubber. Band brakes are applied to the countershaft, to the rear sprocket, to the large gears of the balance gear and to the hubs of the wheels. They are of two varieties,—internal or expanding bands, and external or contracting bands. In the earlier form the external band was commonly used, one end being fixed to the frame of the vehicle, while the other was attached to the operating lever. Application brought the loose end in contact with the revolving drum which caused the band to tend to wind itself around the drum, forming a very effective brake without requiring a great amount of power for operation. This form was faulty when running backward because the friction of the loose end of the band against the drum tended to release the band, with the result that brakes of this kind hold well in one direction but not in the other.

Most forms of band brakes now are attached at the middle of the band, leaving both ends for operation. This insures that no matter which way the vehicle is moving, the brake is equally powerful. In one or more forms the band is provided with two points of support, one of which takes the strain in a forward direction, the other in a reverse; and since both ends are equally operated upon, this form of brake is particularly powerful and requires but the slightest effort on the part of the operator, being practically self applying. On the heavier vehicles internal and external bands

are sometimes applied to the same drum affixed to the hubs. This utilizes double the surface and gives enormous braking power. Many varieties of arrangement are found, but the general principle is the same. Brakes are usually operated by foot levers, but many vehicles have also a hand lever.

Two methods of braking are considered good practice, and most vehicles can be stopped by throttling the engine or applying the proper clutch, so that even if only one brake is used, a second means of control is always present. Some makers believe it is better to fit one brake only, in order that the user, by using it daily, may not only know its condition, but may be trained to use

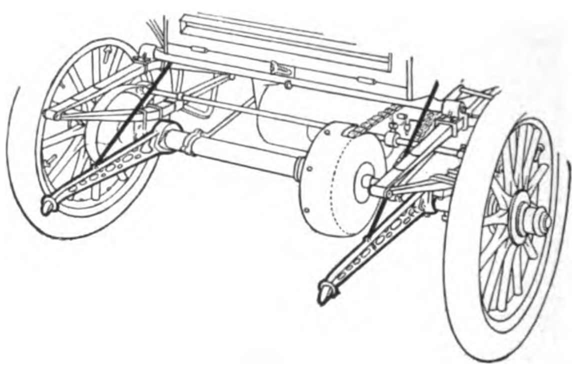


Fig. 50. Drop Brake.

it instantly and automatically, because it has been found that in emergencies the operator forgets special features like an emergency brake, and fails to use them even though he had depended upon them to the neglect of the condition of the more commonly used brake.

To prevent movement backward in case of failure of the brakes, a sprag is commonly used. This is hinged to the rear axle of the vehicle and is let down at the bottom of the hill so that it drags, forming a pawl, which at the first backward movement of the vehicle digs into the ground, effectually stopping movement backward. Some vehicles have the wheels provided with ratchet teeth and a pawl to engage them in the same manner. Others depend on brakes only, but in order that the vehicle may be left

standing on a hill, provide the brake levers with ratchet and pawl to hold them when set.

WHEELS

There are few more important parts in a motor vehicle than the wheels. These are sometimes made of steel, much like bicycle wheels, but the earlier forms were made too light, on which account this style of wheel has been largely condemned. The same fact applies to wooden wheels as commonly used on carriages, with the result that the accepted form to-day is the artillery wheel, a construction having wooden felly and wooden spokes with large butts. These butts join each other forming a complete circle of wood at the hub and are gripped between flanges of metal bolted together through the wood. Any loosening of the spokes at the hub is taken up by tightening the bolts. To the wooden felly is attached the metal rim which engages the pneumatic or solid rubber tire. Some wheels are in use having steel spokes and some experiments have been made with springs instead of spokes in the attempt to gain elasticity in the wheel instead of at the tire. The common wheel, however, is the artillery form described.

It is a noticeable feature of motor vehicle wheels that they are much smaller than the wheels of horse vehicles, although the loads carried are decidedly larger. The reason for this is three-fold. Pneumatic tires are costly, so the vehicle maker to save first cost, uses a small wheel with consequently small and cheap tires, and the buyer having no experience assumes that this must be best, after which the maker excuses himself by saying: "The public wants it." Small wheels are doubtless responsible largely for the great tire and mechanical repairs frequently connected with motor vehicles, and also with the lack of practicability on bad roads, in deep snow, and similar conditions, successfully negotiated by horse vehicles. The second reason for small wheels is the fact that the motor runs more rapidly than the wheels, which necessitates gearing, and large wheels require a greater difference in gear ratios than do small ones, thus increasing the difficulty of the builder. A third reason for small wheels is their greater strength, but it seems wiser to use large wheels and decrease the weight of the

parts to be carried, particularly over the rough roads found in most parts of America.

Tires. Since motor vehicles depend upon the wheels for propulsion, tires having great traction are necessary, particularly if a large proportion of the load is carried on the front wheels, which must be pushed by the rear ones. On this account rubber tires are practically necessary, because steel tires slip on every bit of ice, on iron rails, and even on hard pavements unless caused to grip by spikes or similar projections, which are both rough and noisy. On some vehicles blocks of wood, presenting the end of the grain to the street, are used instead of tires and are found more durable and less expensive than rubber and less noisy than metal, while giving good traction. For trucks, such tires seem well adapted. Wide heavy tires of solid rubber are also used on heavy vehicles, but the pneumatic tire from $2\frac{1}{2}$ to 5 inches in diameter is the prevailing form. These not only give traction but smooth the road very perceptibly, and are therefore well adapted to high speed. Although many other styles are constantly being tried, such as various forms of arched or cushioned tires, also tires having steel springs for resiliency, the pneumatic tire is almost universal.

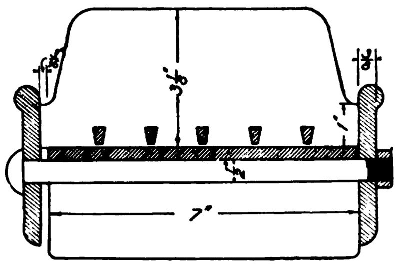


Fig. 51. Solid Rubber Tire for Heavy Vehicle.

This was formerly most common in the single tube shape, but of later years the detachable tire, consisting of an outer shoe or casing with a removable air tube, has become the favorite. Metal rims are nowadays provided with one side removable, which permits the tire to slip off easily, after which the air tube can be repaired or a patch laid on the inner side of the casing. Three common forms of tires are in use at present.

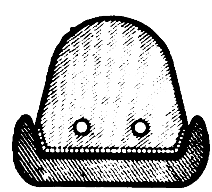


Fig. 52. Solid Rubber Tire for Light Vehicle.

The Clincher tire is so called because as first constructed, its edges were provided with hooks or clinchers, which engaged

similar hooks along the edge of the rim. As now constructed these are practically abutments resting against the upturned edges of the rim, the tire being held down in the rim by its constrictive fabric, which causes it when inflated to shorten in length and grip the rim forcibly. Clincher tires are sometimes held in place more positively by large-headed bolts, which clamp the edges of the casing between the beads and the sides of the rim and prevent the tire from lifting and blowing out of the rim when turning corners at speed, or when partly deflated.

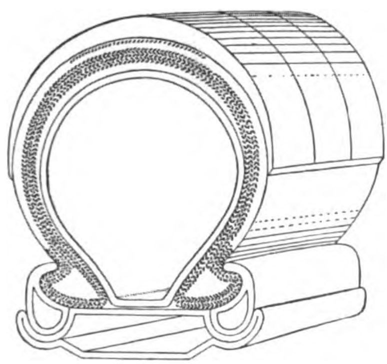


Fig. 53. Clincher Tire.

The wired tire has an endless wire fitted in each edge. This wire is just large enough to pass over the base of the rim and cannot pass over the flange or side when in place. In this form the wire performs the duty of holding the tire to the rim, so that the fabric is called upon only to retain the air pressure within the tire and may therefore be less strained than in the constrictive form where it must both hold the air and also the tire itself, thus performing a double duty. A third form has its edges clamped along the sides of the rim by mechanical means. This is a most positive fastening, effectually preventing creeping, rolling, or blowing off, but it is not so quickly removed for repairs as is the wired tire with removable flange to the rim.

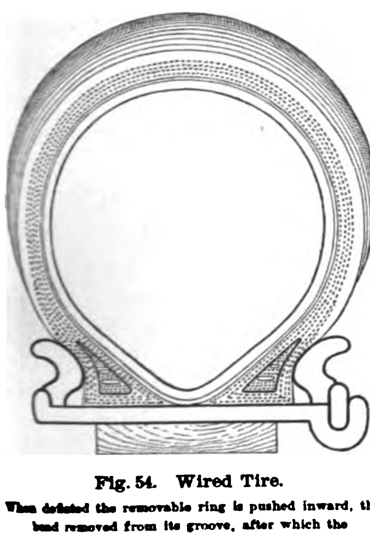


Fig. 54. Wired Tire.
When deflated the removable ring is pushed inward, the band removed from its groove, after which the removable ring and tire slip off freely.

With tires as with wheels, the size is important. The strength of rubber and fabric is quite limited and a surface suffi-

ciently large to support the load without damage to the rubber, must be provided if the tire is to be durable. The constant bending of the tire in the performance of its duty, wears out both fabric and rubber resulting in bursts and blow-outs, while danger of puncture is always present. These objections are best overcome by the use of tires of small diameter in cross section on wheels of large diameter. In this form the contact on the ground is quite long, thus securing a large supporting surface; the wheel revolves less times per mile, thus bending the tire less often, as well as allowing the heat caused by the bending of the tire to dissipate; and finally, the narrow tire is less likely to puncture, for it does not pass over so wide an area and therefore encounters proportionately a less number of causes of puncture. Further, it meets less resistance from mud, sand and gravel, skids less, and therefore is less damaged than a tire which slips and skids more frequently, because it is abuse rather than use which damages any construction. The tire of large section on a small wheel has a bearing more nearly circular on the ground and slides like a snow shoe easily in any direction and thus contributes to skidding, whereas the large wheel with narrow tire is more like a sleigh runner and less likely to skid sidewise. The large wheel rolls out of depressions easily instead of slipping around in them, and it is believed by many that skidding and rapid wear are largely found under the same conditions.

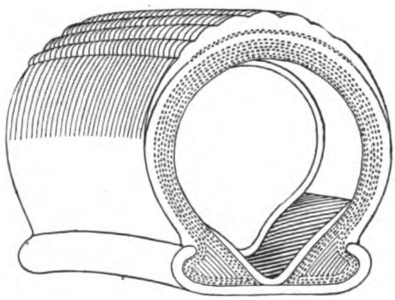


Fig. 55. "G. & J." Tire.

A sudden application of the brake will frequently start skidding, and this is known to conduce to tire destruction. The same remark applies to sudden or jerky applications of the power. On this account the operator should cultivate handling the vehicle smoothly without jerks or abuse. In case of skidding, minimize the trouble by easing the brake or partly shutting off the power, and at the same time swinging the steering wheels, so as to carry the front end to the same side as the rear. Jamming on the brake

or shutting off the power suddenly is liable to make the matter worse.

IGNITION.

One of the most important features of the gas engine is the ignition. It is also the most delicate, and therefore the first place to look for trouble when things go wrong. Present day autos make use of one of three systems of ignition and some are fitted with two forms so as to have reserve if one form fails. In America the make and break spark was the earliest form and has been continued by one maker until the present. This form, also called the wipe, touch, contact or kiss spark, employs two electrodes within the cylinder, one of which is usually insulated in a fixed position, while the other is not insulated, but is movable and arranged to come in contact with the fixed electrode and be separated at the moment the spark is required. In some cases the movable electrode is insulated instead, and in still other cases both electrodes are insulated.

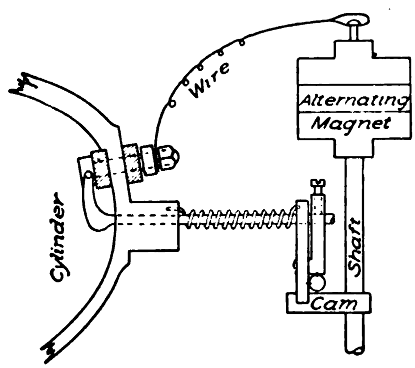


Fig. 56. Make and Break Ignition.

The electric circuit from a battery or other source passes directly through these electrodes, but in order that the spark may be rendered more intense than would otherwise result, it is customary to introduce a simple coil into the circuit, except in such cases as do not need this because of the nature of the generator. The low tension alternating magneto, for example, needs no coil, the windings and core of the armature serving this purpose perfectly. A shunt-wound dynamo will also give a large spark without the use of a coil if the contact is but instantaneous. The coil used with a half dozen cells or with direct-current magnetos or dynamos is identical with that used for lighting gas in dwellings. It consists of a core of soft iron wire, 5 to 8 inches long by about 1 inch in diameter, wrapped with four to ten layers of insulated copper wire $\frac{1}{16}$ inch diameter. When a current passes through this coil, the core is saturated with magnetism, thus storing, as it were, the energy of the current. When the circuit is broken at the electrodes

by separating them, the magnetism in discharging from the core induces a very intense current in the coil, which jumps the gap between the electrodes, making a spark so intensely hot that even heavy cylinder oil is vaporized and any reasonably explosive mixture is ignited with certainty.

The movable electrode is operated by any suitable mechanism, which differs in different designs, but it is a common practice to bring the points together by a strong spring and to separate them by a blow as from a hammer. The coil used must both charge and discharge quickly in order to be suited to high speed work, and since the spark is caused by the discharge, the points must be separated far enough (nearly $\frac{1}{8}$ inch), to give ample room for the spark before the strength of the discharge has been spent, so that in this, as in the vibrator of the ordinary jump spark coil, a sharp, quick break is an essential feature. The moving parts must also be light in order that they may move quickly. The merits of this system have compelled recognition from the best makers and it now seems likely to supersede the jump spark on high grade vehicles.

In France the jump spark was used as early as 1862 by Lenoir, and later by Benz in Germany. It was brought to its most successful form on high speed motors by DeDion and Bouton about 1896 and its success on the many little tricycles turned out by this concern gave it an impetus into public favor, which it has largely since retained. In this system the two electrodes are both fixed, generally in the form of a plug which may be screwed into the wall of the cylinder. Usually one electrode only is insulated, but both are insulated in some cases and connected to the two high tension terminals of the jump spark coil or transformer.

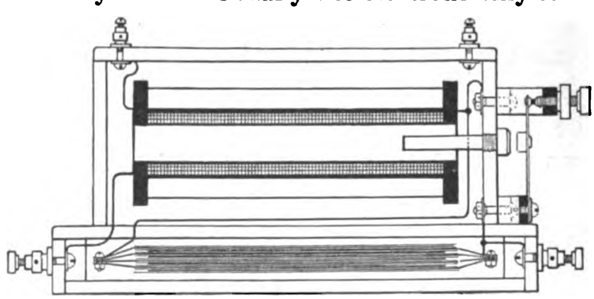


Fig. 57. Section of Jump-Spark Coil.

This coil is quite complicated and consists of a primary winding, forming part of a primary circuit—the equivalent of the circuit employed on the make and break system—a condenser connected across the primary circuit on opposite sides of the circuit breaker, and a secondary coil

LARGEST COMMERCIAL AUTOMOBILE MADE IN AMERICA
Capacity 6 to 8 tons

parallel to the primary, but much longer and of finer wire. The theory of this coil is that when a current is passed through a wire it will induce a current in another wire parallel to the first. When the circuit is broken, the core of the coil being saturated and discharging, as in the primary coil, induces a very strong electric impulse in the long secondary coil, with the result that a spark will jump a considerable gap between the electrodes to which the terminals of the secondary coil are connected. Because of this ability to jump, the system takes its name. In the primary circuit of both systems, the induced current tends to jump where the circuit is broken, but in the secondary circuit the induced current must jump the permanent gap because the terminals do not move.

In order to avoid the large spark at the breaker or vibrator in the primary circuit, a condenser consisting of many layers of tin foil insulated from each other by waxed paper, is arranged with alternate sheets connected to the terminals of the primary circuit on opposite sides of the circuit breaker. This device in effect prevents the discharge of the core from expending itself by producing a current in the primary circuit, and therefore increases or condenses the spark in the secondary circuit.

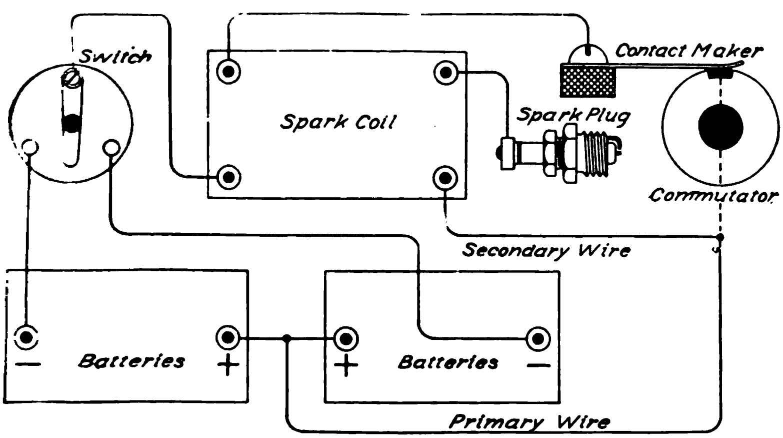


Fig. 58. Wiring Diagram of Jump-Spark Ignition.

In the simplest forms of jump spark ignition, the primary circuit breaker is operated by the mechanism of the engine, which causes the primary circuit to be broken when the spark is desired, just as in the make and break system. Since, however, better re-

sults are obtained by closing and breaking this circuit at a certain rate of speed, than at other rates, it is now most common to employ vibrator coils which have a spring arranged to close the circuit and employ the magnetism of the coil to attract the spring, when the core is saturated, and thus automatically break the circuit, resulting in a continuous vibration or buzzing with an accompanying stream of sparks. With this arrangement it is necessary to break the primary circuit in order to stop the sparks when not wanted, and to this end a timer is operated by the engine instead of the mechanical breaker. By means of this timer the current is connected at the proper time and the vibrator produces one or more sparks, one only at high speeds and several at very low speeds, as when starting. This timer is usually adjustable so that the circuit may be connected earlier or later as compared with the movement of the engine by which arrangement it is possible to produce the spark as desired, either after the piston has passed the dead center, or more or less before the dead center, in some cases 45 degrees ahead.

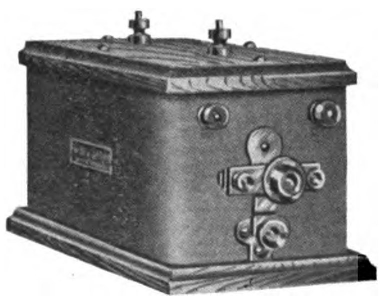


Fig. 59. Jump-Spark Coil.

The object of this advancement is two-fold. The jump spark is so small that the ignition of the explosive charge begins slowly. Second, the time required by the vibrator after the primary circuit is connected, is dependent upon the adjustment of the vibrator but may be such part of a second (usually .004 to .005) that the crank shaft will have moved 5, 10 or even more degrees of angularity before the spark takes place. This lag is particularly noticeable when the vibrator has just broken connection as the timer made connection, the result being that the spark cannot occur until the vibrator spring has made one movement and swung back into contact long enough to charge the coil.

This condition frequently exists with the result that ignition takes place at various times instead of at a fixed point, as with the make and break, and the position of the timer does not represent the average ignition position but rather the advanced position with average cases much behind and extreme cases still more

so. Recognizing this effect, jump spark users are, to some extent, employing a single coil on multiple cylinder engines and distributing the secondary spark from one plug to the next by a well insulated commutator or distributor, so that the average position of ignition may be the same on all cylinders. If separate coils with separate vibrators are used, the difference in the vibrators causes a different average position of ignition and since the multiple point timer cannot be adjusted for one cylinder independent of another, the result is a slight difference in the strength of operation of the different cylinders.

Fig. 60.
Jump Spark Plug.

Since the secondary or high tension current of the jump spark system is of sufficiently high voltage (10,000 to 25,000) to jump the gap between the electrodes while the charge is under compression, it will jump a very large gap in the open air, and must therefore be very carefully insulated. Rubber covered wire ½ inch or more in diameter is commonly used, the wire itself being very small. The plugs are usually of glazed porcelain or of tightly rolled mica or in some instances, of lava or other heat resisting materials. The gap between the electrodes or spark points is usually $\frac{1}{32}$ inch, or slightly more, and a spark to successfully ignite, under the influence of the resistance of the compressed charge, should have sufficient energy to jump ⅜ or ½ inch in the open air. A leakage of electricity from the high tension circuit can usually be seen in the dark by a slightly luminous brush-like discharge, and indicates a point where the insulation should be improved if the best results are desired.

A third system, which has attained some prominence recently, is the magnetic make and break, commonly called the magnetic plug. In this device the magnetism of the primary coil or of an auxiliary primary coil is used to separate the movable electrode from the fixed electrode instead of the separation being made by mechanical means. A timer is necessary in the circuit for the circuit is commonly closed and must be broken by the timer to prevent a continuous succession of sparks. The fault of this device

is that it is not well adapted to currents of varying strength, as for example, the current from a generator driven by the engine; because in starting, the engine cannot be turned fast enough to produce a strong current and the magnetic plug will not operate, or if adjusted to operate on a weak current, it operates continuously on a small saturation of its magnet and breaks the circuit before the core is properly saturated as is required for large spark. To overcome these defects, a two circuit device has been used, both primary, and not complicated. One circuit operates the make and break while the other is a sparking circuit pure and simple. The magnetic plug is believed to combine to a large degree, the good features of both the make and break and jump systems and with suitable development will doubtless have a large future.

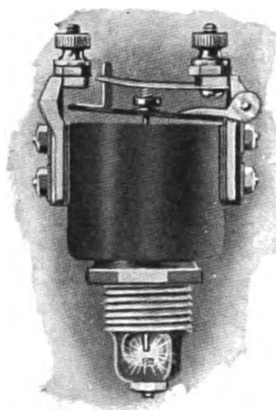


Fig. 61. Magnetic Spark Plug.

The hot tube ignition used by Daimler and others until the beginning of this century is now seldom found.

Galvanic Cells. The earliest source of current was galvanic cells employing a liquid electrolyte. These were sloppy, short lived and very unpleasant to handle, because of the nature of the electrolyte, which was either sulphuric acid, caustic soda, sal ammoniac, or something of this nature. Such batteries have been replaced by dry cells packed solid and simply moistened with a sal ammoniac solution. These are not likely to leak even when placed on their sides because of the small proportion of liquid contained by them. They are cheap in price and because of their use in telephone service, are purchasable almost everywhere. They deliver their output under a tension of one to one and one-half volts and therefore require a less number in series than most wet cells. The ordinary make and break coil is designed to operate with from 6 to 10 volts and 2 or more amperes, although very satisfactory results can be obtained with much less. The jump coil is usually wound for four to eight volts and gives best results if the amperage is quite large. Four to six cells in series is the customary battery,

and good practice makes use of two or more series alternately until all are perceptibly weakened, after which two series are connected in parallel or multiple which doubles the strength (amperage), while maintaining the proper voltage. As the voltage of the cells decreases, connecting an additional cell in series is advisable.

Some users prefer storage cells known as accumulators or secondary batteries. These cells deliver two volts each, and since the internal resistance is low, they will deliver a large quantity of current and thus make a strong spark. They are prepared in small sets suitable for ignition purposes, giving four to ten volts, and although heavy, are quite reliable. Their first cost is greater than dry cells and the cost of recharging is frequently as much as a new set of dry cells. They are probably most satisfactory when used in connection with a direct current magneto or dynamo, by which they are kept fully charged and able to give a strong spark.

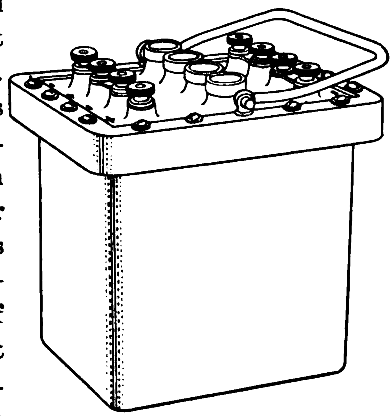


Fig. 62. Accumulator for Gas Engine Ignition.

Mechanical Generators. An early form of mechanical generator was a small shunt-wound dynamo. These are used to a considerable extent and not only give large sparks for both the jump and make and break systems, but also serve to charge batteries, light electric lamps, operate magnetic clutches and even operate magnetic horns.

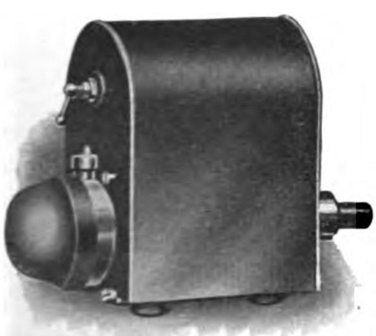


Fig. 63. Alternating-Current Magneto.

The most common form of mechanical generator is the direct-current magneto, which differs from the dynamo in that the field is composed of permanent magnets. These generate current at lower speeds than the dynamo and the current does not increase in quantity with the speed to so large an extent, on which account it is better adapted to the varying conditions of auto work.

It is customary to drive these direct-current generators by friction pulley in contact with the fly-wheel, and some form of governor is provided to withdraw the pulley from contact and thus prevent the generator being driven at excessive speeds, and yet be driven by the small pulley at a speed fast enough to spark when the engine is running slowly. It is quite common to use these devices for starting the engine, but in many cases a battery of dry cells is provided which makes starting somewhat easier.

The alternating magneto will produce two sparks or electrical impulses at each revolution of the armature, and in order that these may occur at the proper time, it is positively driven by gears. This form has no brushes and only one contact from which the live wire is carried. The discharge of the armature serves the same purpose as a spark coil, so no spark coil need be used. As ordinarily made, these are about twice as heavy as the direct-current magneto and will give a spark at as low as 50 or 75 revolutions per minute, whereas the direct-current magneto requires five times this speed to generate a spark sufficiently strong for ignition. Of course, neither magneto will spark properly at such speeds, the alternator usually requiring several hundred revolutions, while the direct-current device or the dynamo are usually driven above 1000.

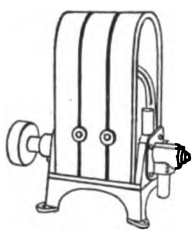


Fig. 64. Direct-Current Magneto.

In case of trouble the brushes or contact points are usually at fault. The contact surfaces will frequently be found dirty and glazed in a manner to prevent the passage of current. Sometimes a bit of iron attracted by the magnetism forms a short circuit across some insulated parts. The bearings should be carefully watched, for if much worn the armature will strike and reduce the speed, or if dry, the friction of the bearings will be greater than that of the driving pulley and the speed will be too low for regular ignition. If the pulley surface is dry, apply belt dressing or a trace of heavy oil; but if greasy, apply powdered common chalk. Resin is sometimes used, but if the fly-wheel surface is hot it is not satisfactory, because it is oily when hot and increases the slipping. These remarks also apply to friction driving gears.

PUMPS.

Pumps are usually one of three varieties, centrifugal, vane, or gear, although reciprocating plunger pumps are occasionally used.

The centrifugal pump is usually 5 or 6 inches in diameter by 1 inch thick, with a revolving vane driven by a shaft which projects through a stuffing box forming one end of the axis of the pump. The water is admitted at a central opening on the opposite side of the case and leaves the case through a tangential opening on the edge. These pumps are not easily clogged, have no parts to wear or be noisy, employ no valves, and do not impede the natural circulation of the water if for any reason they cease running. They are quite usually driven by friction pulley and are generally speeded to 300 revolutions per minute or faster.

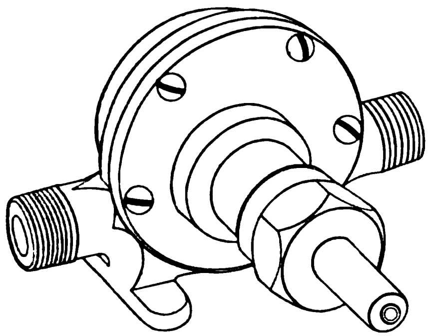


Fig. 65. Vane Pump.

The vane pump is somewhat smaller in diameter but of greater thickness and has the casing eccentric with respect to the shaft. The inner end of the shaft is enlarged concentrically to meet the closest inner surface of the casing, and a slide or vane is forced by the revolution of the shaft alternately back and forth through this enlarged end. This slide is frequently divided at its center and fitted with a spring, which keeps the ends in contact with the inner circumference of the case at all times. The inlet and outlet are tangentially placed on either side the contact point of the enlarged shaft end. The vane ends wear rapidly if the water contains grit, and small obstacles are likely to do damage. This form of pump is usually driven by gears or attached directly to the cam shaft or similar part of the motor.

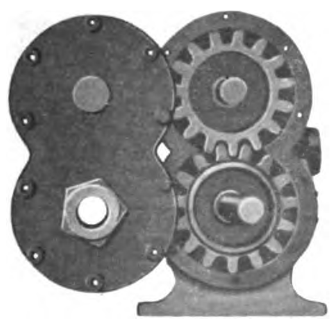


Fig. 66. Gear Pump.

The gear pump consists of two gears of coarse pitch, meshing together and revolving in a figure -8- shaped case, the inlet being on one side of the center, the outlet on the other. The liquid is carried by the tooth spaces around the ends of the 8 but cannot return between the gears because crowded out of the spaces by the

meshing of the teeth. This pump has no valves but like the vane pump, is liable to damage if foreign matter is permitted to enter, and it is of small capacity in proportion to its size. These pump shafts are fitted with stuffing boxes to prevent leakage of water around the shaft. Prepared packings are usually supplied for these boxes, but candle wick filled with tallow or other heavy grease is quite commonly used.

Reciprocating pumps employing piston and check valves are sometimes used but not frequently, although common in launches.

Failure of the pump to work is usually manifested by rapid boiling of the water, smoking of the lubricating oil, and in extreme cases, by loss of power, premature ignition, with pounding, and the symptom of stiffness in the engine when turned by the starting crank. An air or steam trap or pocket is often responsible. Drain the system and refill taking care to get out all air. If clogged by solid material the pump must be opened although turning backwards may relieve it temporarily.

AIR FANS.

For air circulation the ordinary screw-blade fan is most common. This is seldom constructed with less than four blades and generally, in order that it may not be of great thickness in proportion to its diameter, it has eight to twelve or even more blades. It is usually mounted on ball bearings commonly run by V or round belts, although flat belts and spur gears are sometimes used.

Next in frequency of use is the practice of making the spokes of the fly-wheel serve as fan blades and thus avoid the fan with its extra parts, high speed, added bearings and extra oil cups. The use of a centrifugal fan or blower has been attended with good results and is advisable where much pressure is preferred rather than large volume of air. In some instances the energy of the exhaust has been used to induce a current of air and cause this to assist the cooling without additional mechanical parts.

Both pump and fan troubles usually arise from failure to be driven, generally because of slipping of the belt or friction pulley, or because some obstacle impedes the movement of the pump or fan. Pumps sometimes cease to work because they fill with steam, which leaks back through the pump as fast as it is forced forward. The remedy is usually obvious and the trouble is noticed when symptoms of overheating in the engine appear.

BODIES.

The bodies of most autos have one common feature, i. e., the operator's seat. This was formerly placed well to the front, as in horse vehicles, but because of the sudden sidewise movement of the front end, due to steering, this seat was found more comfortable if placed further to the rear, and since many owners are also drivers of their own vehicles, the operator's seat is usually at mid-length of the vehicle. The motor, originally under the floor of the vehicle, is now quite commonly placed vertically in front and covered with a bonnet, which utilizes the available space in front of the operator. On this account additional seating room is secured at the rear, over and frequently behind the rear axle. In some vehicles, as in the Orient, and Adams-Farwell, the motor is at the extreme rear, near the rear axle, while the passengers are carried between the wheels as in the horse vehicle ; a sensible and practical arrangment.

The form of additional seats has been a matter of wide difference of opinion. Some early vehicles had a front seat facing rearward. Later the dos-a-dos was considerably used because it permitted an unbroken space, under both seats, for the mechanism. The dust and exhaust gases behind the vehicle would arise unpleasantly in the faces of the passengers and this rendered such seats unpopular. Rear seats oppositely facing were next tried and this form gave way to the "tonneau," having a seat on each rear corner much resembling two water barrels, from whence the name. A door between these seats, opening at the rear, completed this form, but the necessity of dismounting in the street when the vehicle stood alongside the curb, soon destroyed its popularity.

Side door rears with an occasionally a side door front now prevail. This is a much nearer approach to the common horse surrey, and it seems likely that the satisfaction found by horse users will be accepted by auto users and doors done away with except in the heavier and more elaborate vehicles.

Emergency Seats. For temporary increased seating capacity, emergency seats are quite common. The high cost of the auto as compared with horse vehicles makes it necessary that one vehicle should serve several purposes instead of there being provided a variety of vehicles. When the mechamism was carried at the rear, a front seat usually facing forward and arranged with folding foot

board and back was quite common, This was directly over the front axle, rode unpleasantly, required lap robs to protect ladies' and children's skirts from the wind, and exposed the passengers to dangers of collision and scary horses, as well as getting them in

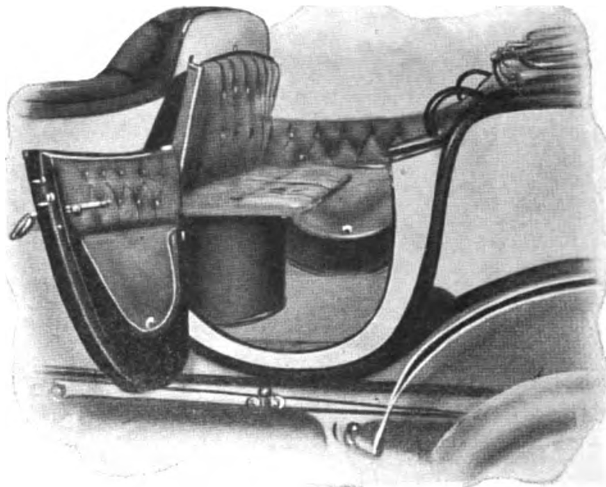


Fig. 67. Arrangement of Extra Seat.

the way of the operator's vision. Seats facing the rear are still used in large tonneaus and serve well.

The folding rear has been recently introduced and converts the runabout into a surry in a practical, comfortable and inexpensive

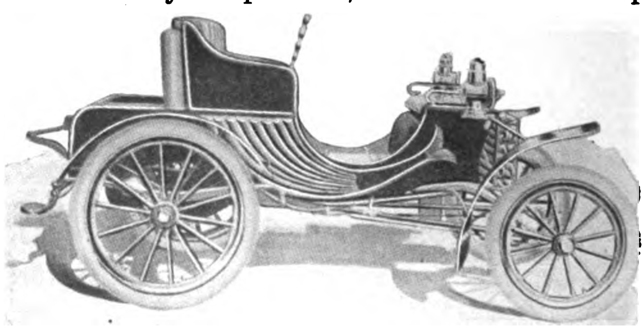


Fig. 68. Folding Rear Seat Phaeton.

manner. Unlike a detachable tonneau, it is always present when wanted, and quickly closed when not wanted. It adds little extra weight, requires no mechanical work to open or close and bids fair to be a permanent device.

In some forms of vehicles notably cabs and broughams, intended to be driven by drivers for hire, the operator's seat is at the extreme front or at the extreme rear as in similar horse vehicles. It seems evident that similar requirements will largely dictate similar forms in autos as in horse vehicles, and mechanics will doubtless be able to accommodate the mechanism to the bodies without great deviation from those vehicle forms proved by years best suited to the needs of the public.

Tops. Auto tops are substantially the equivalent of those used on horse vehicles although generally larger and more strongly made. They are either single or double, of the folding or cape top variety, with occasionally a canopy top and quite frequently a standing top with curtains or with glass windows, forming a

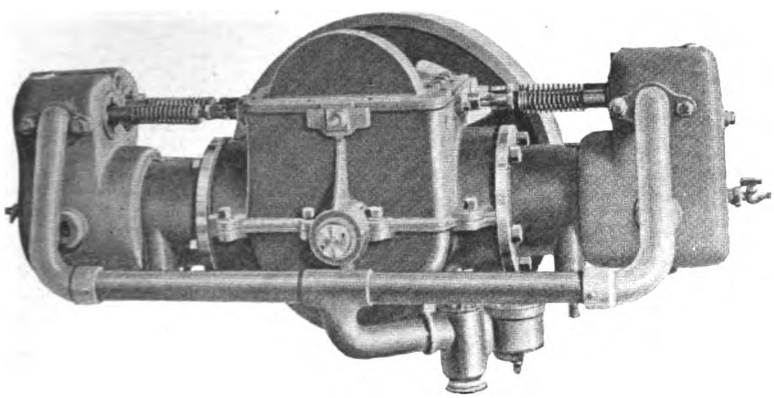


Fig. 69. Double Opposed Motor.

completely enclosed vehicle. High speeds in cold weather have made some form of protection desirable, so glass plates are fitted in front of the driver and are used either with or without the top as desired. They should be folding or removable because the air carried behind them is dust laden in dry weather and in rain or snow one can not well see through them.

Location of Mechanism. Several arrangements of mechanism are in use. In the earlier forms the motors were placed under the operator's seat because this was near to the driven axle and was the most available space unused by the passengers. As motors increased in size this space was not sufficient, so the body of the vehicle was extended backward, the full height of the seat, giving much additional room. Additional passengers were either placed

in front or on top of this rear extension, with the result that, as motors were made still larger, they were crowded down under the floor in a dark and inaccessible position as well as exposed to the mud and dust of the road. These faults compelled recognition, and, coupled with the unpleasant riding qualities of the front end, caused the motor to be placed at the front with the transmission gear and similar fittings under the floor as in common use at present. In a few instances designers were able to provide sufficient power in the space under the seat and thus avoided placing the motor in front, far removed from its point of application of power, and the success of such arrangement with the success of rear-

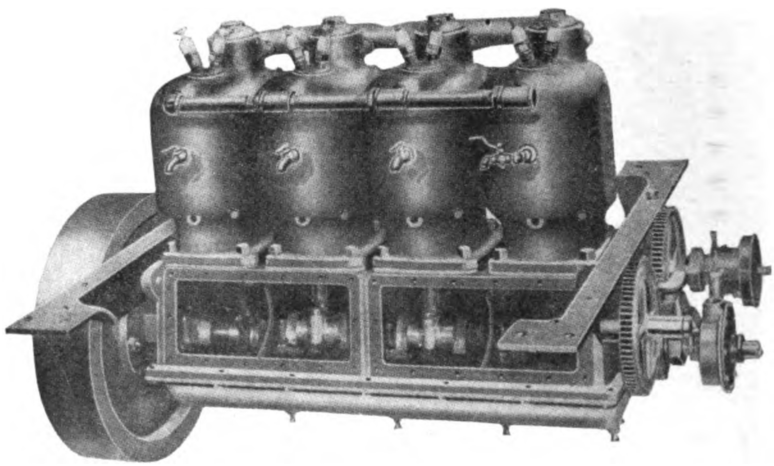


Fig. 70. Vertical Four-Cylinder Engine.

placed motors renders it likely that in the near future the motor at the rear will be considered, as it undoubtedly is, the best engineering practice.

Most designers began by using single-cylinder motors which were placed horizontally lengthwise of the vehicle, because this placing secures low center of gravity and least vibration. Increased power was secured by doubling the cylinders, but since a twin motor of the four-cycle type ignites in irregular sequence if the cranks are opposed, the double opposed motor became the accepted two-cylinder form. This ignites one cylinder each revolution instead of one and one-half revolution followed by one-half revolution apart, as in the twin-cylinder type.

Doubling the twin motor gave the common four-cylinder en-

gine, usually placed vertically, with crank shaft lengthwise the vehicle. The reason for this arrangement is that the width of an ordinary vehicle is not sufficient to place the motor crosswise, with crank shaft parallel to rear axle, as in the single and double cylinder arrangement. The triple cylinder motor is used by some makers who believe that it secures multiple cylinder results with the least complication and is therefore the most desirable form. Such engines, with cylinders of 5-inch bore, are placed crosswise of the vehicle as in the Duryea while four cylinders of nearly 4-inch bore are placed crosswise at the front in one or two air cooled

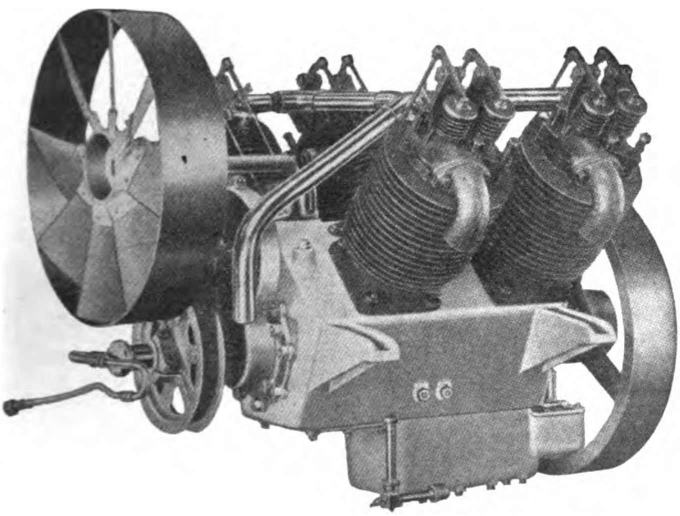


Fig. 71. Marmon Inclined-Cylinder Engine.

vehicles, as in the Marion. But the usual arrangement is lengthwise of the vehicle in vertical position when more than two cylinders are used. In the Marmon the cylinders are inclined two to each side about 30 degrees from a vertical position, while in the Duryea, the cylinders are inclined to the rear, 30 degrees from horizontal. In the Adams-Farwell, either three or five cylinders are used, equally spaced around a vertical axis and arranged to revolve in a horizontal plane. The weight of the cylinders avoids need for a fly wheel and their motion gives an efficient air cooling without fans or other mechanism.

In one or more instances the cylinders have been placed equally distant around their axis of revolution and parallel thereto,

which arrangement also secures steady rotation without a fly-wheel, and efficient air cooling. The auto is largely the sport of the wealthy and as is the case with all new things, is frequently provided, to the point of vulgarity, with various fittings and trimmings quite often made to sell rather than to use, and bought rather for ostentation than for any real service. A considerable business is done in these fittings, some of which are quite elaborate and expensive.

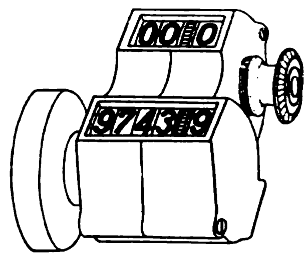


Fig. 72. Odometer.

FITTINGS.

Odometers are arranged with a single dial to give the total distance travelled or with a secondary dial to record the distance of each

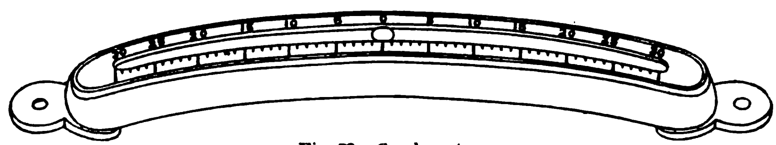


Fig. 73. Gradometer.

trip. Speed indicators show at a glance the speed at which the vehicle is traveling at any time, while clocks affixed to the dash board relieve the operator of the necessity of consulting his watch. Gradometers indicate the angle of the hill with more or less accuracy. Manometers tell the story of the water circulation. Voltmeters and ammeters advise concerning the electric circuit and various gauges and glasses show the action of the lubrication, the amount of fuel and water, and the air pressure in the air brake reservoir or gasolene tank as the case may be. Spark coils and acetylene generators, storage tanks and storage batteries are quite frequently in evidence while horns, gongs, or whistles complete the list. Some of the latter are numerous enough and properly toned and arranged to permit playing a tune. All are well in their place but add needlessly to an already

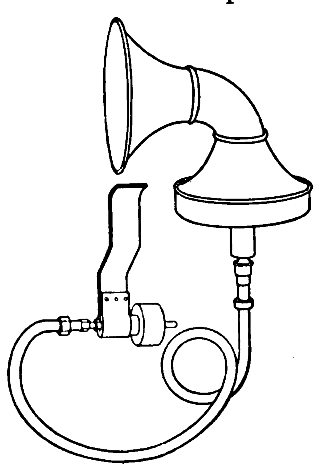


Fig. 74. Siren Horn.

A pulley running on the tire of the vehicle rapidly revolves a disk filled with holes. The result is a loud sound.

complicated vehicle and are not in accord with the simplicity which

Fig. 75. Three-Toned Horn.

must accompany an extended use of this valuable invention.

SHOCK ABSORBERS.

The high speeds frequently attained by motor vehicles greatly magnify inequalities of the road surface, with the result that the springs are violently compressed and rebound disagreeably, sometimes breaking. To prevent this, friction surfaces have been applied, which, while they permit yielding, dampen or deaden the spring action and render the vehicle more comfortable. Some forms of these employ pistons with valves or passages which permit free movement in one direction, but not in the other. It is urged against this that at high speed the second inequality is met before the springs have recovered their position, so they are unable to perform their duty.

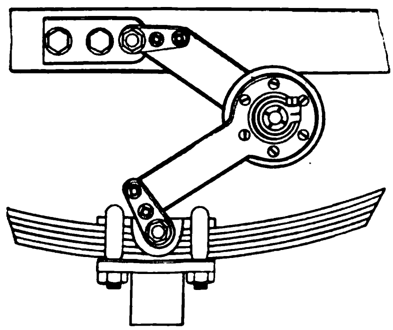


Fig. 76. Shock Absorber.

Springs. The comfort and durability of the vehicle depends largely upon the springs, although following cycle practice, many constructors have depended upon tires for this service. As in carriages, three forms of springs are quite common with a number of less used forms. The full elliptic has always had recognition and is a serviceable spring, but does not offer the rigidity sidewise that the half elliptic secures. It is quite essential that ther ear axle at its sprocket should remain in line with the body or frame which carries the front sprocket, as otherwise the chain may jump off. The full elliptic requires the use of reaches or radius rods to hold the axle in position, but the semi-elliptic is usually fastened to the framework at one end, while the other end is carried by a swinging shackle. Side springs fastened to the body at their centers, and to the axle at their ends, have been much used on cheap constructions, and although not the best form, have given good service.

Spirial springs are sometimes used, principally as an accessory, to modify the action of the main spring or to assist it to carry the load. The high speeds frequently attained by autos, together with the small wheels used, demand exceptionally good spring suspension, which has heretofore been neglected, but is receiving more attention at present. Rubber buffers have been frequently used to prevent overloaded springs, and many a bent or broken axle has been due to improper spring design. In case of a broken spring it is usually possible to fill in the space with a block of wood which will permit the vehicle to be used.

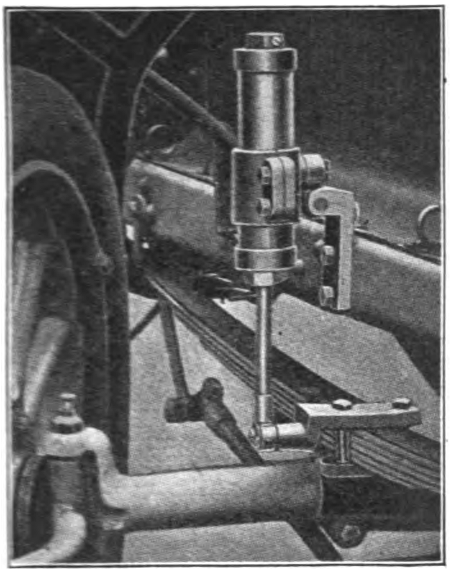


Fig. 77. Air-Cushion Shock Absorber.

Much of the comfort of a vehicle depends upon the upholstering. Deep springs in the cushions and backs add greatly to the ease of riding. This is particularly true in going over gutters or water bars where stiff, firm backs, as found in many tonneaus, transmit to the rider severe jolts, which, if the backs are high, are felt as disagreeable jerks at the neck. For high speed, low backs are more comfortable because they permit the entire spinal column to yield instead of the neck only. Deep springs, however, ease such objectionable features greatly.

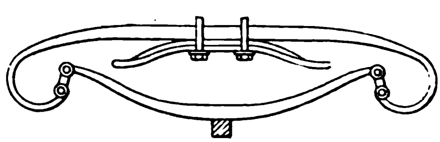
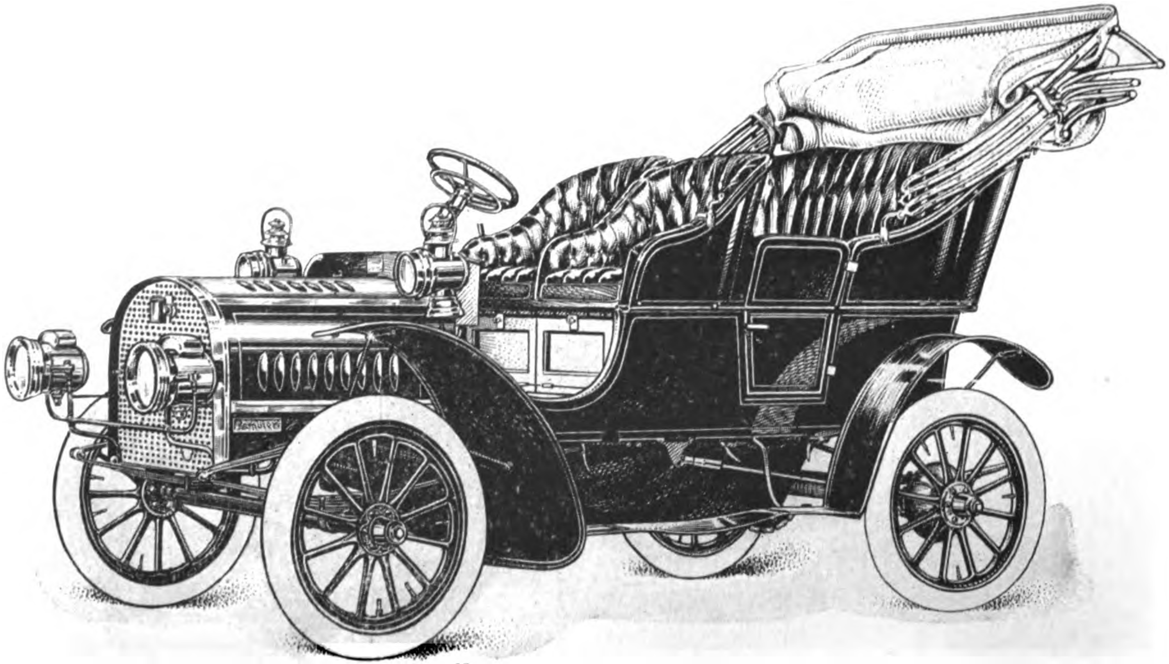


Fig. 78. Rear Spring with Buffer.

Since the auto is necessarily associated with oil, and is driven at high speeds in all weathers, the upholstering is best of leather or pantasote, so that it may not absorb oil nor dirt nor be soaked and damaged by water.

BEARINGS.

Auto bearings are in general of three kinds, plain, ball and roller. The plain or common carriage bearing gives good satisfac-



SURREY TYPE OF RAMBLER AUTOMOBILE
Thos. B. Jeffrey & Co.

tion if frequently oiled and is of low first cost and needs few repairs. Rear axles which revolve are frequently mounted in plain bearings, usually of bronze or babbitt, with equally good results.

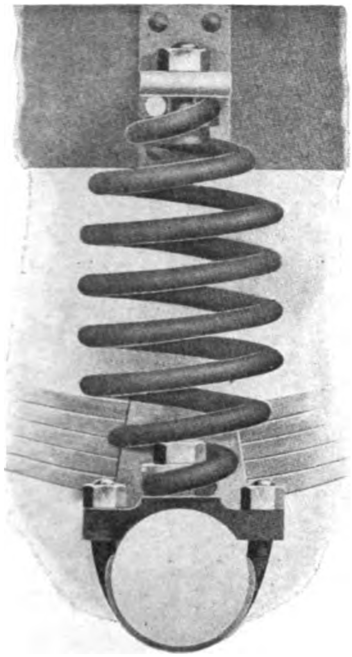


Fig. 79. Spiral Equalizing Spring.

For light vehicles, particularly with small power, as the light steam and electric carriages, ball bearings are quite common. The small area of the ball races requires that the balls, cups and cones be extremely hard in order to give service, and a broken ball frequently damages the bearing. The operator should listen for grinding or squeaking in the ball bearings and stop and remove the broken ball before further damage is done. For heavier loads, roller bearings are common. These are of several varieties, one well known form employing flexible rollers made by rolling a strip of metal into a spiral. The rollers are usually guided by cages to keep them parallel, and if not so guided should be quite short, preferably of a length not greater than their diameter. Rollers are usually

Fig. 80. Ball Bearing.

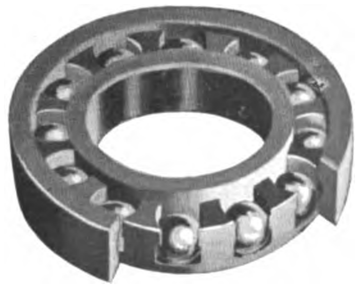


Fig. 81. Annular Ball Bearing.

hardened and ground. Conical rollers, also held in cages, are much used and are particularly adapted for places where the strain comes in various directions, as in the hubs of wheels. Ball or roller

bearings are much used to receive the thrust of bevel gears or friction disks.

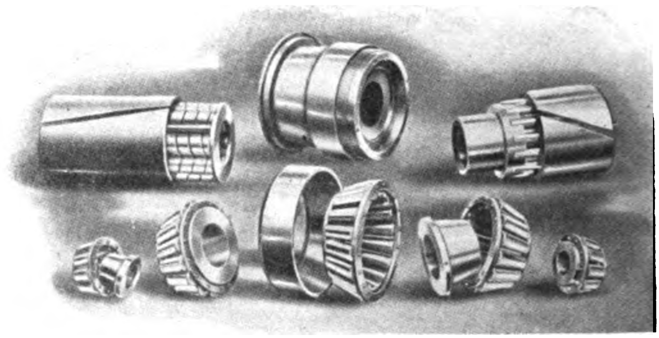


Fig. 82. Plain, Flexible, and Conical Roller Bearings.

LAMPS.

The law in most places requires autos to carry lamps, although other vehicles do not as a rule carry them and cannot be seen by the auto driver unless he is provided with a searchlight able to light the road a great distance ahead. Without this assistance he may be unaware that a scary horse is doing damage and therefore unable to stop or govern himself accordingly. The searchlight throws a powerful beam which blinds the horse driver and renders him likely to leave the road. The safest arrangement is for all vehicles to carry a light on dark roads in order that each driver may be aware of the presence of the other.

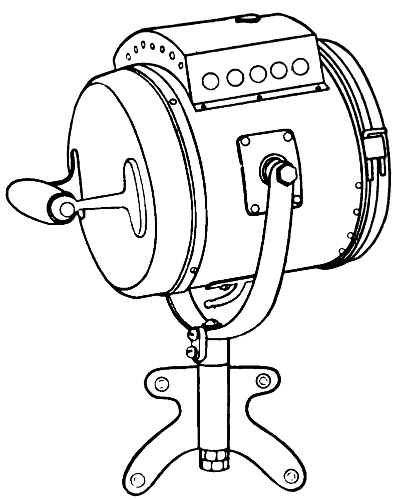


Fig. 83. Automobile Searchlight.

OPERATION.

The operation of a vehicle depends much upon its particular design and information is usually supplied by the maker. In general, it is necessary to turn on the electric current, the liquid fuel, open the throttle, and turn the starting crank. After the motor

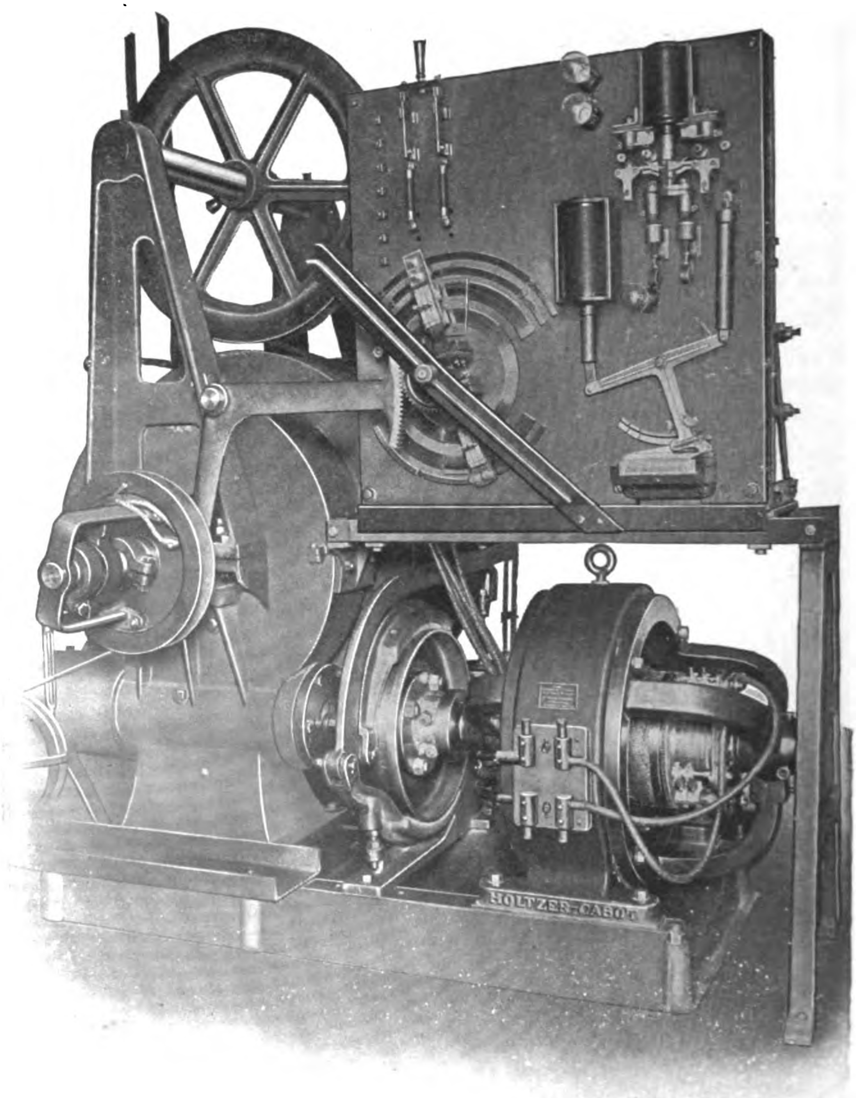
starts, adjust the gasolene to give best results, throttle the motor to suit, and set the low clutch gently. This throws a load on the the motor, to overcome which the throttle should be opened correspondingly. As the vehicle starts, feel of the steering to know that the vehicle is under control. As the speed increases change to a higher gear, the object of the skilled driver being to use the high gear as much as possible, in order that the motor may make as few revolutions per mile as may be, thus saving fuel and wear. In no event should the motor be choked down till it is jerky or liable to stop, for this may result in a stop in front of a train or in some similar dangerous and undesirable place.

The brake should be tested at the first opportunity and particularly before starting down a steep hill, so that it may be known to be in perfect order, for next to the ability to go, is the ability to control and stop. If the brake is faulty, the vehicle may be stopped by stopping the motor with the low speed clutch engaged and the clutch may also be used as a brake either instead of the regular brake or in conjunction with it on hills, thus forming a second brake, and one that is usually in order, as proved by the ability to climb hills. The low clutch is very effective and subjects the vehicle to a decided strain on which account it should be applied gently lest a chain be broken or gears stripped. In such an event the vehicle should be turned crosswise the road into the bank if circumstances permit. If the speed is too fast and the road is clear, and straight, the bottom of a hill may be safely reached but this dangerous chance should never be attempted except as a last resort. A properly powered vehicle will climb hills with little loss of time, so there is no need to rush down hill at a dangerous rate or with the vehicle beyond control to make up time.

The operator should learn to recognize by ear the proper running of all parts of the vehicle and recognize instantly any deviation therefrom. He should also recognize by the way the vehicle starts or coasts whether it runs freely or not, and by the feel whether a tire is flat or not. Lack of lubrication in the engine or vehicle adds much to the labor and expense and should be sought for and remedied. A weak spark causes a weak engine and signifies that either the batteries need renewal, the generator brushes need cleaning, the driving device is not doing its duty, or the electrical wires and connections are at fault. An excess of lubricating

oil will sometimes coat the interior of the cylinder with carbon, which should be removed by scraping, the cylinder heads being taken out for this purpose. The mixture should be right and the proper proportion of gasolene vapor and air must be determined by adjustment and trial. Usually more is required on a dry day than on a wet day because on a wet day the water vapor displaces some of the oxygen, so that less gasolene can be burned. Too much fuel weakens the mixture and soots the plugs and walls.

The cooling devices should be watched that the fan does not stop nor the water tank get empty, although in either case the engine may be run a short distance without damage before it gets hot enough to destroy the lubrication. The gasolene tank and piping should be so simple that it can be easily watched, for a leak is not only wasteful, but dangerous, because of possible fire. The tank should never be exposed to heat or burning vapor and tanks containing pressure are inadvisable because of the more rapid leak in such cases. For cold weather or for starting, a gasolene of low specific gravity, numbered high on the Baumé scale, is best, but a heavier liquid will give more power per gallon. With a hot engine, kerosene can generally be used, a fact which will enable one sometimes to get home after finding the gasolene tank empty. Take great care that the battery is never left on a closed circuit for this quickly destroys its efficiency.



MOTOR DIRECT-CONNECTED TO ELEVATOR.
Holtzer-Cabot Electric Company.

ELEVATORS

The elevator as a modern appliance has become a very important factor in business life. Fifty years ago it was comparatively unnecessary, and in the few instances in which it was in use, it was considered more of a luxury than a necessity. The earliest form of elevator was used only for merchandise, and the power employed was derived from a revolving shaft through the medium of leather belts running over pulleys. The introduction of steam, however, as a source of power for its operation, made a change in the speed that could be attained, and enlarged considerably its field of operation. It then began to be used for passengers as well as goods.

EARLY STEAM ELEVATORS

The application of steam for this purpose was made in a modified form, the engine employed being a double cylinder engine with the cranks set at right angles to avoid centering, but the valve motion was the principal feature of difference. Of course, many experiments were tried in the beginning, but what we shall describe here is that form of valve motion which became generally adopted. The distributing valves were of a special type, resembling more than anything one ordinary D-valve within another, and the number of ports in the cylinders were four each; Nos. 1 and 3 being the usual distributing ports carrying steam to each end of the cylinder, and Nos. 2 and 4 being used alternately as steam and exhaust ports. The starting and stopping was done by means of a change valve,

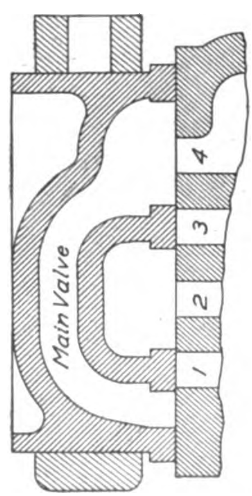


Fig. 1. Distributing Valve.

which alternately, at the will of the operator, converted one of the latter mentioned ports into a steam supply port and the other into

an exhaust. These valves — one change and two distributing — were all three contained within one steam chest, and the pressure of the steam from the boiler was always on them, holding them to their seats. The change valve, however, was the only one which opened a port directly into the steam chest. The operation of these valves and their arrangement will be readily seen by reference to the accompanying illustration.

It will be seen from the illustration that with this arrangement of valves there could be no lap or lead in the distributing valves on the cylinder faces, because the valves had to act alternately for steam supply and exhaust, and any lap or lead that might be given them for operation in one direction would produce a distorted action when used for running in the reverse direction. The consequence was that the engine of this type was not economi-

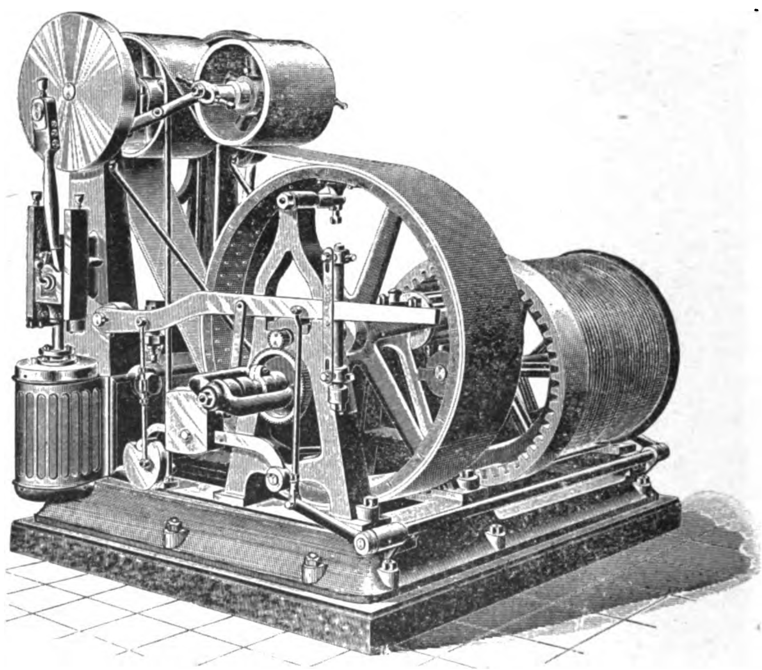


Fig. 2. Spur-Gear Elevator Engine.

cal in its use of steam; and while it was a great favorite at the time of its introduction, and for many years afterward (because of a lack of anything better) it has, since the introduction of the

hydraulic and modern types of electric elevators, almost gone out of use.

At the time of its introduction it was used entirely in connection with spur gearing, the first types of this engine being made to drive a pulley on the crank shaft which was belted to a larger pulley running in stands on the engine bed, the shaft which this pulley drove having on its end a spur pinion meshing into an internal gear, which was bolted to the end of a hoisting drum or spool which wound up the cable or wire rope, to one end of which the traveling platform or cage was attached. This wire rope passed from the hoisting drum up the hatchway and over grooved wheels or sheaves at the top of hatchway and then down to the cage, and the change valve, by means of which the steam was shut off or turned into the engine to operate it in either direction, was connected to a wire rope of smaller diameter, which led up the hatchway within easy reach of the operator, and the pulling of this rope up or down was sufficient to start the elevator in either direction.

The amount of steam, however, under pressure, required to operate the engine when lowering a load, was so much less than that needed for hoisting, that in order to prevent the engine from racing and lowering at an undue speed, the change valve was always adjusted to give a very small opening into the steam supply when running in this direction, and in addition to that a certain amount of lap had to be given to the valve on the exhaust side, so as to choke the exhaust and thereby retard the descent. There was some danger of overloading of the engine, for in case an overload was placed on the cage, of course an attempt to lift it would fail, but in lowering, especially when the steam was shut off quickly, the pressure of the confined steam in the cylinders would sometimes exceed that in the steam chest, in which case the distributing valves on the cylinders would be lifted from their seats, and where they were fitted to work in a yoke or buckle, at the end of the valve stem, they would remain off the seat, when once lifted therefrom, until replaced. There was nothing then to hold the load but the brake, and to obviate this trouble it was customary in many cases to bolt to the bottom part of the steam chest an angle piece fitting closely at the back of the valve. This piece being

stationary, and its vertical side parallel with the cylinder face, the valve worked up and down between it and the valve seat, and it prevented the valve from being raised from its seat.

The brake used on this type of engine was a flexible band of steel, which was lined with hard maple in short sections and fastened to the band by screws. A suitable lever for applying the brake, with a heavy cast-iron weight on the end of the lever and proper adjustments for taking up the wear, completed the outfit. The brake was always applied by means of the weight on the end of the brake lever and was released by means of a heart-shaped cam fastened to a pedestal or stand on the engine bed and operated by the yoke or automatic stop, which, being connected to the operating cable in the hatchway, before described, was always actuated when the hand cable was pulled to the center of its throw.

The pistons of these engines were usually very simple in construction; they consisted of a disc or block of cast iron properly bored and fitted to the piston rod and turned with grooves to receive the piston rings, which were then sprung over the block into their respective grooves. They were made slightly eccentric, being thicker on the side which was left uncut, and were usually turned little larger than the bore of the cylinder. When they were cut, a piece had to be taken out, leaving a space of about $\frac{3}{16}$ inch between the cut ends, and the rings consequently had to be squeezed together or compressed in order to enter the ends of the cylinder, and this caused a constant outward pressure of the piston rings. They were made two in number; in some cases three, and were usually from $\frac{3}{8}$ to $\frac{5}{8}$ inch wide.

Owing to the confined space into which these engines had to be put at times, it became necessary to reduce them somewhat in height in order to get them into low basements when desired. The consequence was that the connecting rods were not always as long as the best practice would dictate, and as a consequence of this, and the constant reversing of the engine, it was frequently found somewhat difficult to make them run quiet. Now, however, with care, this result can generally be attained.

Another cause of hammering in this type of engine was a lack of care on the part of the manufacturer to so proportion the length of bore of cylinder as to allow the outer piston rings to just

pass over the end of the bore at the end of each stroke. This length of bore, of course, was determined at the time of counter-boring the cylinders, and where the bore was so long that the piston rings did not quite reach the ends of it, they would in time, as the bore of the cylinder enlarged from constant wear, leave a shoulder at each end. Against this shoulder the rings would strike at the end of each stroke, and if the engineer was not posted on this peculiarity, he would probably try for months to get his rods to run perfectly quiet without good results. The only remedy in a case of this kind would be to take out the pistons and file the shoulders, before mentioned, but it would be only temporary. The proper way to get rid of the evil entirely would be to counterbore the cylinders a little more, but it was a job that was attended with considerable difficulty with the engine in place, hence the first method would be found most satisfactory.

The cross heads and guides were similar to those of most engines, whether horizontal or vertical, and differed with the ideas and taste of the maker. Several different arrangements were used; some with plain straight slides, some with V-shaped; but the most popular was that of the bored guides, for cross heads, using a bronze shoe with proper adjustments for wear. These engines would often run as high as 500 r. p. m. at full speed.

One feature of this engine which frequently caused great annoyance was the running off of the belt which connected the pulley on the crank or engine shaft with the large pulley, before mentioned, running on a shaft in stands on the bed. There would seem at first sight to be no good reason why a belt of this kind should not run well and in line, but frequently carelessness in workmanship was the cause of this, for if the pulleys themselves were of equal diameter at each side, and the shafts were not perfectly aligned with one another, it would cause this trouble; and while the belt might be adjusted to run well in one direction, it would run off the pulley when the engine was reversed, there being a "tightener" for the purpose of taking up the slack of the belt, which could be adjusted so as to cause the belt to run well in one direction. The distance between centers of shafts being short, the belt was necessarily short too, seldom exceeding 19 feet in entire length, and it was always endless, that is, without seam or lacing.

The writer has frequently seen on some of the older types of these engines a pulley that was larger on one side than the other; this also would cause the trouble.

Another defect in this engine was the liability, when the belt had been in use a great while and neglected, for it to become dry and cracked, and if it broke either when lifting or lowering a heavy load, there was a chance of the cage falling, there being nothing to hold it in that case but the brake. To automatically apply the brake and at the same time shut off steam, in case of an accident of this nature, there was attached, to one of the arms carrying the idler, a vertical rod The lower end was attached to the cam operating the brake; the upper part of this rod was hollow and the lower part telescoped into it. A collar and set screw on the lower rod being set in the proper position would receive the end of the upper rod on its face, in case the belt should break or come apart, for the great weight of the idler pulley would cause it to fall, carrying the arm to which the upper part of this rod was attached. This then would throw the brake cam around in the position to apply the brake, and at the same time shut off the steam, thus stopping the engine also.

This pulley, which performed the double office of tightener and as an adjustment for the direction of the belt, was very necessary, because as the belt stretched from constant use, this idler, running on top of it, and being made very heavy for the purpose, would take up the slack of the belt, causing it to have greater contact with the pulleys. The arms, which carried the shaft upon which it ran, were attached to the upper part of the engine frame and extended outwards toward the rear of the engine, and were of such a length as to leave the pulley in the right position upon the belt just between the engine pulley and the larger pulley in the stands on the engine bed. Sometimes, however, a sudden stoppage of the engine would cause this tightener to jump away from the belt and then drop back upon it, and this feature had a tendency to cause the belt to break whenever it became weakened in any part.

To prevent this jumping of the idler, which also had a bad effect on the stopping of the engine, spiral springs were sometimes attached to these arms and carried down to a convenient point below where they were attached either to the bed of the engine, or to

the wrought-iron braces which stayed the upright frame to the bed. Turn buckles were provided to give the springs proper tension, and this remedied the difficulty just related.

When these engines were at rest the steam chest was always full of steam and ready at any moment to start upon the change valve being opened in the proper direction. As this steam chest radiated considerable heat, there was always more or less water of condensation in it. A drain pipe was run from the bottom of the steam chest to a steam trap, which was set considerably below the level of the bottom of steam chest, and the water escaped to this steam trap.

The automatic stop was a screw provided with a traveling nut and adjustable set collars. This screw was a sleeve which usually ran upon a long stud bolted to one of the stands in which the larger pulley shaft ran, and it was geared to the pulley shaft by means of

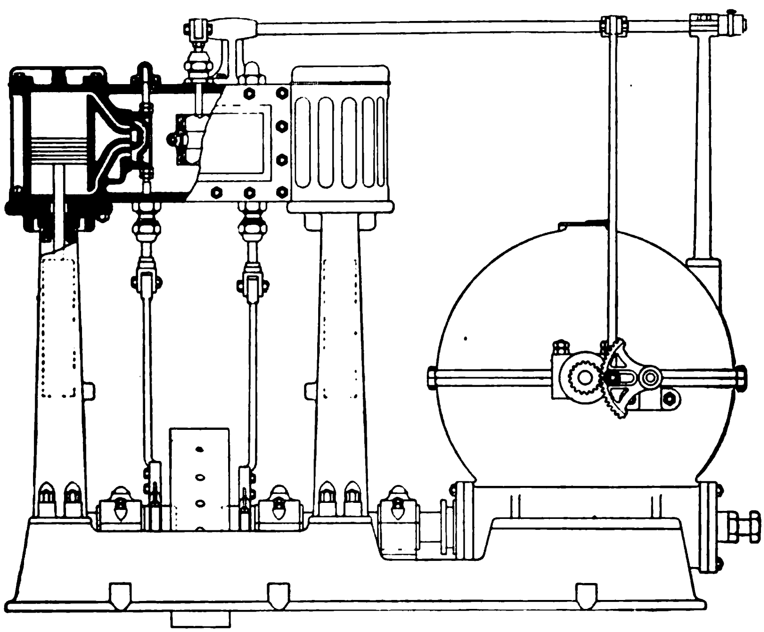


Fig. 3. Elevator Engine with Worm Gear.

a spur gear and pinion, which were so proportioned as to give this automatic screw about the same speed as the drum shaft. The traveling nut was so arranged that at either end of the run it would

come in contact with the set collars, which had to be set just to the right position to gear with this traveling nut. They each had a tooth which interlocked when the traveling nut and collar were brought together. By this means, the traveling nut was made to revolve, and as it turned, the automatic yoke, which was connected to the starting lever by means of a link connection, operated the change valve and applied the brake at the same time, thereby stopping the engine at the limit of its run. This end was also attained by means of stop buttons on the operating cable, which were made so as to clamp the cable wherever they were placed and tightened up, and a striker or arm attached to the cage so as to slide up and down on the operating cable freely. Whenever the striker came in contact with one of these stop buttons it pulled the cable the same as the attendant would, and thereby also shut off steam and applied the brake. The operations were identical in each case, except in the method of arriving at results. A pressure of from 60 to 90 pounds of steam was usually carried at the boiler.

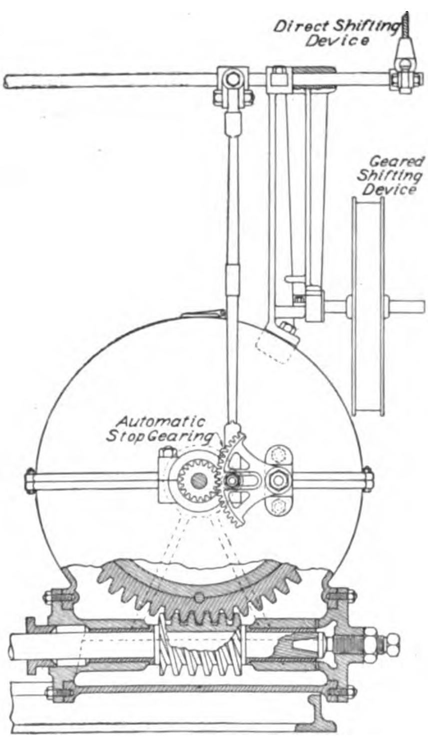


Fig. 4. Worm Gear in Housing.

The lubrication of the wrist and cross head pins, eccentric straps, etc., was usually supplied by means of compression grease cups. This method was adopted on the score of economy and cleanliness; the valves were lubricated by means of a self-feeding cylinder lubricator.

The chief difficulty with the spur gear type of engine was that of low pressure and overloading. It sometimes happened that when there was no steam on the engine at all, the car being left at one of the upper stories,

an ignorant attendant would put load on the car and pull the operating cable. The brake being released, the load would run the engine backwards and run to the bottom violently. Of course, when these engines and their peculiarities became well known, accidents of this kind were less frequent, and taking it altogether, the service rendered by these engines was invaluable. Being the most rapid up to the time of their introduction and for a long time afterward, they were a favorite for many years, the principal objection to them being the cost of operation in comparison with other methods introduced later.

Later on a modification of this engine was used for passenger service. The changes consisted of the use of a worm gear in place of the spur gearing just described, and owing to the location of the worm shaft it necessitated the use of an engine with the cylinders inverted, and placed at the top of the engine instead of below as in the original form. This arrangement has some advantages for passenger work, as the liability to run down, which always exists with a hoisting machine where spur gearing is used, was eliminated. It was also considered safer and more desirable for passenger use on account of its smoother action and the fact that the breakage of one or two teeth in the gear would not cause the platform to descend rapidly. The other characteristics of the engine were not changed.

WATER BALANCE ELEVATOR

Contemporary with this engine, which attained its greatest popularity during the 70's, there was introduced a form of hydraulic elevator which at one time bid fair to be a successful rival of the steam engine. It was called the water balance elevator. It consisted of the usual cage or cab in which the passengers rode, the cables necessary for hoisting which passed up the top of the hatchway in the usual manner and over sheaves, thence down into a large metal tube or well hole, and attached to the other end of these cables was a large bucket that nearly filled the well hole just mentioned. At the top of the well hole and above the highest point to which the bucket traveled, there was a tank containing water supplied by means of a steam pump. At the bottom of the bucket was a discharge valve, which as well as the valve at the

bottom of the tank just mentioned, were operated by means of pedals located in the cab.

The operator by pressing the appropriate pedal with his foot would discharge water into the bucket from the tank above. When sufficient water had accumulated in the bucket to more than balance the weight of the cage and its occupants, the elevator would begin to move, the water in the bucket forming a counterbalance weight and virtually dropping down the well hole dragging the cage upwards, and vice versa, when the water was allowed to discharge itself from the bucket it would become lighter than the cage and the cage would drop. This water having been discharged into a tank at the bottom of the well hole, would be pumped again into the overhead tank.

The speed of this elevator was unlimited, and was governed entirely by the use of a powerful brake gripping the slides or rails on which the cage traveled. This brake was arranged by means of very strong springs which always held the brake on, and had to be released and held off by hand to obtain any movement of the cab when the conditions for motion were right; and in letting go of the brake, it applied itself with sufficient power to stop the elevator.

This form of elevator was found to be very expensive, both to install and operate, and moreover, was dangerous in the hands of unskilled men, and it soon went out of favor upon the introduction of the horizontal hydraulic elevator. The latter was originally the invention of William Armstrong, a man prominent among mechanical engineers in Great Britain.

HORIZONTAL HYDRAULIC ELEVATORS

The first elevator of this type was used for the purpose of hoisting stones from a quarry in Yorkshire, but its utility as an elevator for merchandise was soon recognized and it began to be used extensively for this purpose in that country, and it was along in the early '70's that it was first introduced into the United States. The earlier machines of this type were usually operated by water pressure obtained from the city mains. The machine consisted of a cast iron cylinder, the bore and length of which varied according to surrounding conditions, being chiefly governed by the water

ESCALATORS IN A CITY STORE.

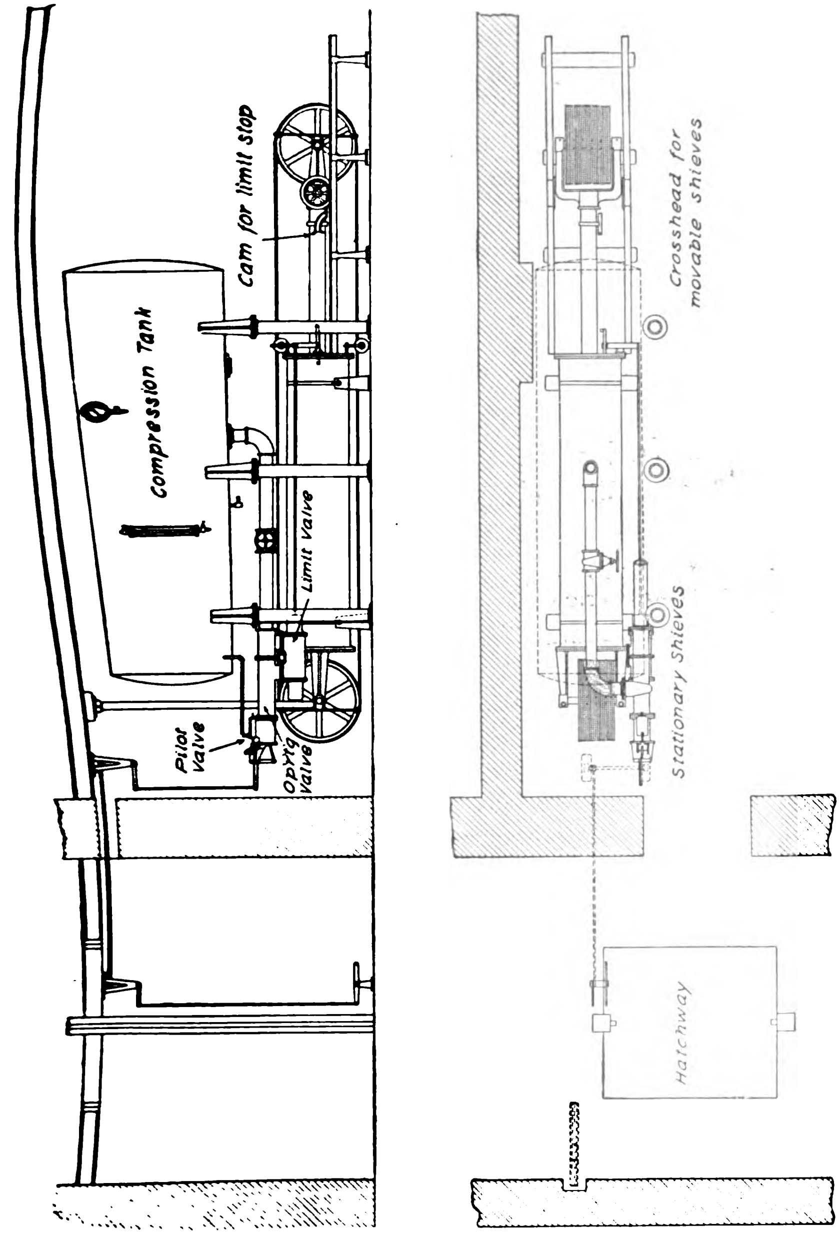


Fig. 5. Plan and Elevation of Horizontal Hydraulic Elevator.

pressure available and the height of the building in which it was used. A piston, fitting closely in this cylinder, was made water tight by means of suitable packing. There was a piston rod and cross head which carried a set of traveling sheaves, and a set of fixed sheaves. The cross head traveled on a track provided for the purpose, which acted both as a support and guide for same. The cable which hoisted and lowered the cage, passed up the hatchway in the usual manner over sheaves at the top of same, thence down to one of the fixed sheaves below on the end of the machine. From there it passed successively along under the machine, around one of the movable sheaves on the cross head, back to one of the fixed sheaves at end of machine and so on three or four times, and the other end was finally made fast to the hydraulic engine. This arrangement of rope and sheaves was exactly like a block and tackle, the cage being attached to the loose or running end of the

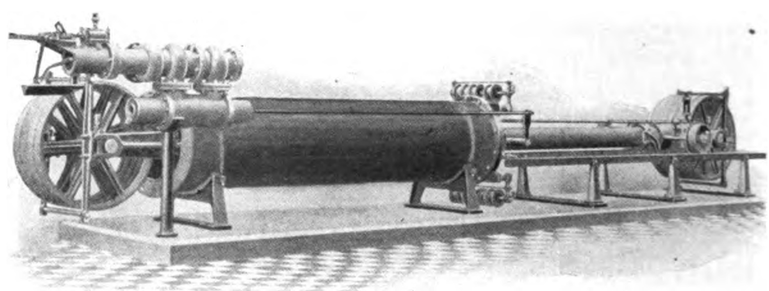


Fig. 6. Horizontal Hydraulic Elevator.

rope. Now when water pressure was applied to the piston, it would pull these sheaves apart, causing the end of the cable in the hatchway to raise, with the cage attached, at a speed much faster than that at which the piston traveled, the difference in speed being governed by the number of sheaves collectively on the machine. For instance, if the cross head had four movable sheaves traveling with it, and at the fixed end of the machine there were four sheaves, the ratio or difference between the speed of cage and that of the piston would be 8:1; in other words, the cage would travel eight times as fast as the piston, and eight times as far. The ratios more generally used are from 4:1 to 10:1, depending on the speed required and the load to be lifted. With this arrangement when

connected to the city mains, the water, after being used, was wasted or allowed to run to the sewer. Later on, the introduction of the roof tank permitted water to be used over and over again, the same as in the water balance elevator. A still greater advantage was gained by the introduction of what was called the pressure tank. This was a modification of the accumulator so much used in Europe in connection with hydraulic presses, and consisted of a reservoir that was fitted with a plunger of large area, which worked vertically through a tight stuffing box, and having on its end an enormous weight or load of cast iron. Water being pumped into this accumulator, raised the plunger with its load, and when draft was made upon it, it would force this water out into the cylinder of the hydraulic ram with a pressure equivalent to that of the load carried.

The pressure tank was similar in arrangement, except that the compression of air above the water gave the pressure required. A cylindrical tank properly braced and stayed was used, with inlet and outlet pipes and water glass to show the height of water in the tank, and a pressure gauge. Air would be pumped into the tank up to a moderate pressure, afterwards water would be pumped in, and this water further compressing the air, would produce an ultimate pressure of anywhere from 100 to 150 pounds per square inch. The inlet and outlet pipes for the water were directly at the bottom of the tank to prevent the escape of any of the air, and when water was drawn off from this tank in the cylinder of the hydraulic engine, the drop in pressure would not be more than a very few pounds, owing to the expansibility of the air above the water, about one-third of the total contents of the tank being air under pressure.

This arrangement enabled higher speeds than was admissible with the street main service, the street pressure of many cities being low; in fact those having a high pressure—anything from 60 to 100 pounds—being rare. Moreover this arrangement had other features which were desirable, the absence of water hammer in the pipes being one, the using of the same water over and over being another, and the ability to have the most useful pressure being a third. With the higher pressure, cylinders of a smaller

diameter could be used, and consequently a less amount of water also.

The operation of the hydraulic elevator was by means of a two-way valve, the most improved type of which consisted of a cast iron cylinder with a brass lining, which was perforated opposite the openings or branch pipes in the cast iron body. Inside this brass lining was a plunger with leather cup packings held in position by discs of brass, which were so arranged as to cut off the supply of water gradually so as to produce an even and gentle stop. Where the supply was taken from the city main an additional precaution was taken of using an air chamber on the supply pipe near the operating valve. The office of this was to prevent violent shocks in the pipe from the sudden stoppage of the flow of water through the same, caused by shutting the operating valve quickly. The water in the main, when the valve was closed, would continue its onward course up into the air chamber, the air in which being compressed, would act similarly to a spring, gradually retarding the flow of the water and restoring its equilibrium, but in the case of the compression tank it acted of itself as a huge air chamber.

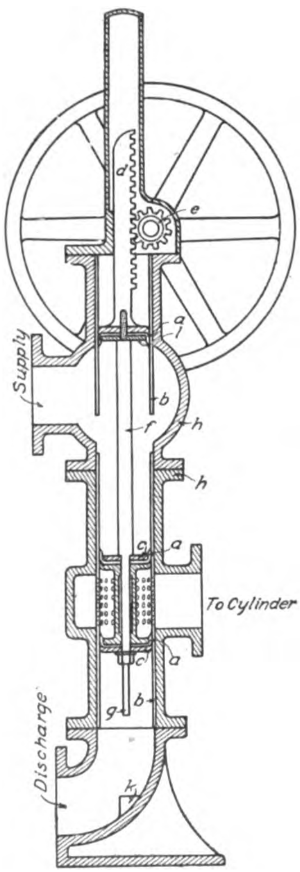


Fig. 7. Two-Way Operating Valve.

a, Leather packing cups; *b*, Brass lining of valve; *c*, Brass plates supporting leather cups. *d*, Brass rack in which pinion works to lift and depress the plunger; *e*, Steel pinion, *f*, Steel stem to which all the parts of the plunger are attached. *g*, Extended end of steel plunger which serves as a stop to downward stroke of plunger by striking on *k*. *h*, Cast iron body of valve.

Depressing the plunger allows the water to flow from supply to cylinder. Raising plunger allows water to discharge from cylinder.

With the higher pressure obtained by use of the tank, greater speeds could be attained, frequently as high as 300 or 400 feet per minute, while with the street main system it rarely exceeded 150 feet per minute, and frequently was as low as 50. The compression and roof tanks were usually kept supplied with water by

means of powerful steam pumps, the change of level of water in the tanks being made to automatically turn on steam or shut it off. These pumps, therefore, were not obliged to run constantly, but cnly when the supply of water in the tanks became somewhat depleted, the pumps running simply long enough to supply the deficiency.

When the higher speeds were found desirable and attained, some better means of operating the elevators than the hand cable became a necessity, and the invention of the lever operating device followed. With it came the pilot valve. This was a small auxiliary valve attached to the main operating valve which obtained its power from the pressure tank. The operator in the cab moving his lever, would open the small pilot valve, which in turn admitted water to a piston on the stem of the main operating valve, the pressure of the water moving this piston in either direction as desired, and with it the main plunger of the operating valve. The pilot valve itself and its connection with the plunger of the main operating valve is so constructed that a partial movement of the operating lever would produce a partial opening of the pilot valve, and in turn, a partial opening of the main valve, if so desired. The full opening and closing were obtained by the full movement of the operating lever.

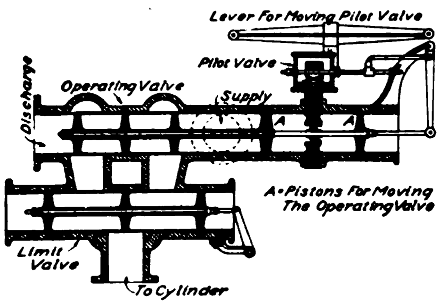


Fig. 8. Auxiliary and Operating Valves.

VERTICAL HYDRAULIC ELEVATORS

The horizontal hydraulic elevator had not been in use very long, when Mr. C. W. Baldwin, of New York, conceived the idea of using a vertical cylinder. This was not entirely new, as they had been used in Europe, but not exactly in the manner in which he proposed to use his. The advantage of his form of hydraulic elevator was that it took up less room in the building, because it could be set up in the same hatchway with the traveling cage, in

one corner of the well hole, and for the sake of economy in space it was usually made with a ratio of from 2:1 to 4:1, instead of from 6:1 to 10:1 as with the horizontal hydraulic. The consequence was that the cylinders were necessarily quite long, though smaller in diameter than the horizontal machine. They differed also from the horizontal in the fact that they did not use any guide ways for the cross head.

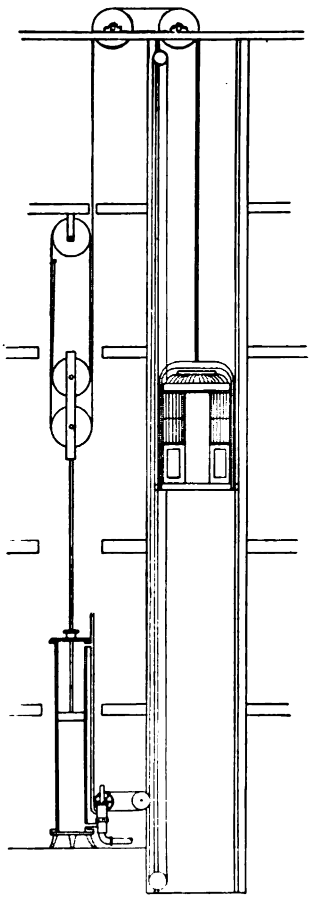


Fig. 9. Vertical Hydraulic Elevator.

The cylinder being set vertical and a fixed sheave directly above it, the end of the hoist cables were made fast to a beam overhead and led thence down to the cross head and around the sheave in same, and up again over the fixed sheave before mentioned, thence over the sheave in hatchway directly above cage. This gave the machine a speed ratio of 2 to 1, and the piston would travel just half the distance of the cage, but it was found that a great loss of pressure occurred at the beginning of the travel, owing to the top of the cylinder being so high above the level of supply. To equalize this, the discharged water was returned through a circulating pipe to the bottom of the piston, instead of discharging it into the surge tank or sewer immediately after it was used. By this means the weight of the water beneath the piston was used to equalize the pressure, but as this water beneath the piston was held there by atmospheric pressure until discharged, it was found that the length of the vertical cylinder could not be more than 33 feet at sea level, or its equivalent in other places. This limited the length of vertical cylinder that could be used, so that the ratio of this type of machine was governed somewhat by this.

But with all these machines, both horizontal and vertical, where the pressure was comparatively low, a great loss of power was caused by the friction of the piston in the cylinder, and the flow of the water through the pipes, as well as the difference in weight of the cables, depending on whether they were hanging in the hatchway on the side of the car or on that of the machine. These cables, which were usually four in number, and sometimes more (and generally of about $\frac{5}{8}$ inch diameter, weighing about $\frac{3}{4}$ of a pound to the foot), would, when the car or cage was at the top of the hatchway all hang down towards the machine, and in the case of a building say 100 feet high would amount to over 400 pounds. Now while as a measure of economy, it was desirable to counterbalance the weight of the cage, it could not be done very closely with this difference in the weight of the cables on one side or the other, according as the cage was at the lower or upper landing. Hence, some means of counteracting this was found desirable, and it was done by hanging chains in the hatchway, one end of them being attached to the wall of the hatchway about half way up the run or travel of the cage, their other ends being attached to the bottom of the cage. It will readily be seen that when the platform or cage was down at the bottom of the run, and consequently the cables on the car side hanging down in the hatchway and equalizing the weight of those on the other side, the chains would be hanging on the wall, but that when the cage was at the top of the hatchway and the weight of the cables preponderating on the other side, these chains would be hanging on the bottom of the cage, thus offsetting the weight of the cables. By this means closer counterpoising could be obtained, and the desirability of this method of counterpoising, in after years, when much taller buildings came into existence, may very readily be seen. In fact, it became quite indispensable in the case of buildings of 17 or 18 stories.

Later on, the introduction of the electric elevator and the claim made for its economy of operation caused elevator builders to look for more economical methods of operating the hydraulic elevators. One of the chief drawbacks to economy in the hydraulic elevator was the fact that the same amount of water had to be used per trip regardless of the load, and the introducers of the

electric elevators made the claim that an amount of current proportional to the load carried was all that was used.

The introduction of the high pressure water system in the city of London had attracted considerable attention in engineering circles, and the use of elevators in connection therewith had shown that a greater economy was possible with a higher pressure, owing to reduced area of cylinder, there being less friction and smaller consumption of water. The system of high pressures was introduced here, but it has not realized all that was expected of it. The enormous expense connected with the installation and maintenance are the chief drawbacks, but during the time that was devoted to experimenting with the high pressure systems, one or two types of elevators were evolved that gave considerable satisfaction, one of these being that of using a vertical cylinder with a ram, the weight of which was sufficient to lift the cage with its load. The hoisting of the load, therefore, was done by discharging the water from the cylinder, and when the platform or cage was to be lowered it was accomplished by turning the water pressure against the end of the ram and lifting it. This ram was geared in the usual manner by means of a cross head and sheaves having a ratio of anywhere from 2:1 to 6:1.

Other schemes were devised for economy, one of which was to have two or more tanks at varying pressures, one tank having say 100 pounds pressure, a second 150, and using one or the other according to the load to be lifted, an automatic operating valve being used in connection therewith.

Another form of hydraulic elevator, which has always been very popular in Europe, was the plunger machine or ram. This consisted of a hollow plunger, which passed through a stuffing box in the top of the cylinder which was let down into the ground, the depth of same being the length of run from lower to upper landings, the platform or cage being set on top of this ram. When water was let into the cylinder the pressure of same against the bottom end of the ram forced it up out of the cylinder, and the cage with it, to the top of the building, the lowering being done by allowing the water to afterwards escape. The form of valve and its operation was the same in this case as in that of the other types of hydraulic elevators.

This style, of elevator, however, from the point of economy had one objectionable feature that was peculiar to itself, and which was more noticeable in the higher runs or upper stories of buildings. The plunger being hollow, to insure lightness, had a certain amount of buoyancy when wholly immersed, but when run partially or entirely out of the cylinder, this buoyancy necessarily decreased, and consequently the lifting power of the elevator became less and less as it reached the upper stories of the building. It consequently could not be counterbalanced very closely, because if that were done the plunger, in descending to the lower story, would come to a point where it would stop of itself because of its inability to displace the water in the cylinder. This was a matter that entered largely into the calculation of the area of plunger when arranging the proportions of cylinder and plunger, in relation to the pressure of water to be used.

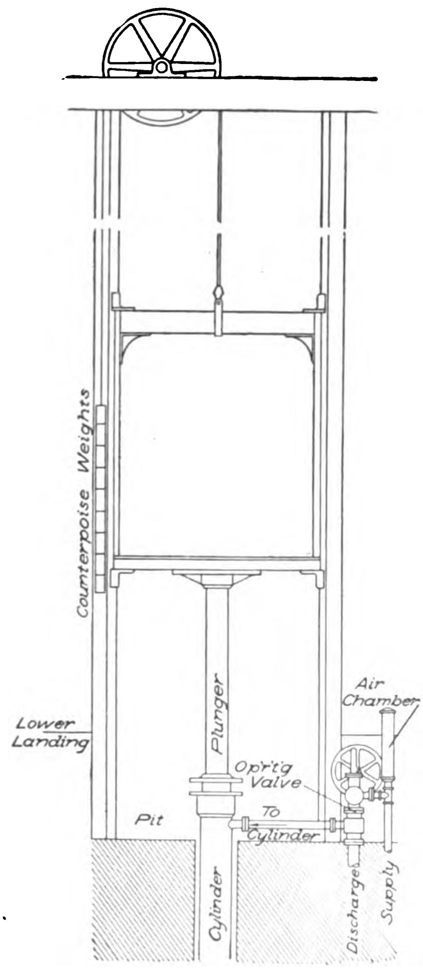


Fig. 10. Plunger Elevator.

The earlier elevators of this type were usually made with a cast-iron plunger, which as before stated, was hollow, and, owing to the brittleness of cast iron, had to be re-enforced by running a heavy wrought iron rod up through the middle of the plunger, the lower end passing through the bottom end of the plunger, the upper end being made fast to the floor of the cage. Without this the sudden

opening of the operating valve would allow the escape of water from the cylinder for descent, and when the cage was in the upper story it was liable to cause the plunger to break off. Such an accident as this occurred some years ago in Paris, causing the loss of one or more lives.

In the case just mentioned, the wrought iron rod in the center of the plunger was absent, its absence being a fault in the design of the machine. To-day, however, with the introduction of Bessemer steel tubing, the necessity for the center rod does not exist, the ends of the tubes being threaded internally, and a male coupling being used inside the pipe. The joints in the cast iron plunger were made by boring out the ends of the sections of the plungers and inserting a thimble nicely fitted, which entered each end of the adjacent sections to a distance of 3 or 4 inches, the ends of the sections of the plunger themselves being faced or squared off perfectly in the lathe, and the whole being put together with a hydraulic cement composed of litharge and red lead mixed with boiled linseed oil, or Japan varnish. These machines are very much in vogue to-day for short runs, and despite their lack of economy in operation, which must necessarily exist owing to the conditions described, a company has within the past few years been formed for the exclusive manufacture of this style of elevator.

PACKING AND LUBRICATION

Of course, in the manufacture of all the styles of hydraulic elevators here described, a very important feature is the condition of the bore of the cylinders and the external diameters of the plungers. It is absolutely essential that both cylinders and plungers shall be parallel and smooth, any inequalities or inaccuracy causing a waste of the water used in operating them, and one of the most essential features in their care is the proper, and even, setting up of the packing, both in the glands of the plunger machine and in the piston of the cylinder machine.

Many forms of packing have been devised, the earliest being the leather cup, which is almost as old as the hydraulic press, in which latter it proved to be the most successful packing ever devised. In a hydraulic press, the ram or plunger travels a very short distance and very slowly, and under exceeding great

pressure, but with the lower pressures used in hydraulic elevators, and with the greater rapidity and distance of travel of the piston, this style of packing was not found to be as long lived as could be desired. Hence, various other means were devised to overcome the defects found to exist in the leather cup. One of the best was that of using a leather cup exactly as the original, but smaller than the diameter of the cylinder by an inch or inch and a quarter, and to fill up the space between the leather cup and the bore of cylinder, rings of ordinary square pump piston packing, made of alternate layers of rubber and canvas, were used. These were held in place by means of a follower ring, and through the web of the piston leading directly behind the leather cup, small holes were drilled which permitted the water in the cylinder under pressure to obtain access behind the leather. This pressure forced the leather outwards against the aforesaid rings of piston packing, pressing them against the bore of the cylinder, and allowing the passage of the piston in a water tight condition.

This form of packing was used very largely in the vertical hydraulics, described above, and introduced by Mr. Baldwin, but this form of elevator had one great disadvantage over the horizontal type of machine, in that both ends of the cylinder were closed, and these conditions did not permit of proper lubrication. Hence, after machines of this type had run a few years the cylinders became badly scored or grooved, and there was a great leakage of water past the piston, and the only remedy was the reboring of the cylinders. In many cases, especially where elevators of this type had been installed where the water pressure was low, the cylinders had been designed with such thin metal in the walls that they would not admit of reboring. In some cases, engineers had tried to introduce a lubricant in the water used to operate the elevators, but with no very marked success.

With the horizontal machines, however, one end of the cylinders being open, lubrication became an easier problem to solve. In these machines, owing to the greater diameter of cylinder, the leather cup and piston packing was not so readily applied and in lieu thereof, several forms of packing were adopted by different makers, each having his own particular choice. In some cases, plaited hemp was used. Others used the square piston packing

made of rubber and canvas before described. Still others used rubber cord; some used it in the square strips and others round with alternate layers of square piston packing, and each of these had its own particular merits and advocates.

The piston had to be made with an annular space for the reception of this packing, so shaped that the pressure of the necessary follower ring, which was essential to the tightening up of the packing, caused it to be forced outwards against the internal sides of the cylinder. This follower ring was made with a roomy groove in that part of it which extended outside beyond the packing, and from this groove extended a pipe leading out beyond the open mouth of the cylinder to the cross head where a large compression grease cup was fastened and kept filled with grease. The tightening of a screw in this grease cup forced the grease through the pipe into the groove in the follower, thereby keeping the cylinder constantly lubricated at every stroke, and to prevent its escape through the open end of cylinder and consequent waste, a "wiper" or single ring of packing was used with an auxiliary follower ring to tighten it up as required.

There is a peculiarity about the lubrication of the cylinders and plungers of hydraulic elevators not generally known to the persons in charge of these machines, which is that nothing but purely animal oil or grease will give perfect lubrication.

Since the introduction of oils and greases that were partially or wholly composed of products of petroleum, their cheapness and adaptability to revolving shafts and bearings has made them a general favorite, but however well adapted they were for lubrication of this nature, they were wholly unfit where water came in contact with the surface, and that is why they were not suited for hydraulic elevators. Each time the cylinder was filled with water, or when, in the case of the plunger elevators, the plunger became immersed in the cylinder, grease or oil that had been applied during the stroke would float away in the water, leaving the bore of the cylinder or external surface of the plunger entirely bare. To obviate this, it was necessary to use a purely animal oil or grease, which, being a better resistant of water, would remain on the metallic surface for several strokes of the piston or plunger, as the

case might be, and consequently was more economical and more satisfactory.

LIMIT VALVES

For limiting the travel of the cage to the upper and lower landings, in other words, to cause the water to be automatically shut off at these points independently of the efforts of the operator, the earlier hydraulic elevators depended entirely on button stops on the operating cable, working in conjunction with a striking arm on the cage.

In all elevators it is the custom, in putting on the operating cable, to arrange it in such a way that pulling down on the standing part of the cable which is used by the operator causes a motion of the elevator in an opposite direction, and vice versa. For instance, were the operator to pull the cable down, the car would rise. Now at a proper place on this cable is fastened a sort of clamp, being made in halves for the greater convenience in putting it on, and the two halves being fastened together with bolts. When put in place on the cable and clamped tightly there, it is immovable except with the cable. An arm of wrought iron is fastened to some convenient part of the cage sufficiently high to be out of the way of the operator, and this arm is formed at one end into a ring which slips freely over the operating cable as the car travels, and strikes the button just described, on arrival at either end of the run, moving the cable exactly as the operator would do it to the central or stop position.

This arrangement worked very nicely and filled all requirements as long as the operating cable was in good condition, but it was found in course of time that, as the operating cable wore or its condition deteriorated from any cause (the principal one being dampness in the pit at lower landing), it was liable to break, and this always occurred when it was least expected, the result being disastrous in every instance. In some cases the piston would come out at the end of the cylinder, allowing the water of the cylinder to escape, causing serious damage, for it would continue to flow through the supply pipe, and at the same time the cage would be run violently into the sheaves at the top of the hatchway, often breaking them and causing other serious damage, and in the case

of the plunger elevators, the plunger would come out of the cylinder, allowing the water to escape in like manner.

To prevent this, various expedients were devised, among them being the limit valve. This was an auxiliary valve placed between the operating valve and the cylinder, and was so arranged in the case of the horizontal hydraulic elevator that cams attached to the piston rod at either end—one near the cross head and another near the piston—would engage an arm on a rock shaft, moving the arm so as to cause it to close the limit valve, and thereby prevent the ingress or egress of water to or from the cylinder according as the cage was at the upper or lower limit of its run. The earlier forms of these valves were made single acting, that is to say, they simply closed the pipe between the operating valve and cylinder, and they were so arranged that they did not entirely close it unless the car went a few inches beyond the landing in either direction. When this occurred, the valve had to be opened by hand in order to give the cage headway in the opposite direction, and this was found to be a decided disadvantage.

Then another form of valve was devised of the two-way type, taking water through one passage from the operating valve for hoisting, and discharging it through another from the cylinder through the operating valve also, thus giving the operating valve control of the water at all points, excepting the upper and lower limits of the run. With this arrangement it was possible to run down or up to the extreme limit, allowing the limit valves to take care of the stops at either end, because in this case when the limit valve shut off the supply of water for hoisting at the upper landing, it left the opening for lowering still open and vice versa.

This form of limit valve proved all that was required of it, but even *it* was liable to derangement, so to overcome these difficulties and to make it simply impossible for the elevator to run beyond its limit, more care was taken with having the cylinders of the exact length required for the run, plus the length of the piston, and across the open end of the cylinder and spanning the piston rod, which was allowed to pass freely through it, was a very heavy bar of cast iron, which projected some inches beyond the outer diameter of the cylinder. Similar projections were made on the cylinder head on each side to correspond with the ends of the bar,

just described, and running along longitudinally between them were very heavy rods of wrought iron or Bessemer steel threaded at each end. The ends of these rods passed through holes in the lugs cast on the cylinder head and through the ends of this bar, and nuts on the ends of the rods bound the bar and cylinder head together. A rubber bumper was put around the piston rod, clamped there firmly, and set partially in a recess made in the hub of the piston, and upon the arrival of the piston at the end of the run this rubber bumper would come up hard against the heavy bar of cast iron, which being made amply strong for the service it was to perform, prevented the travel of the piston any farther, and in like manner the piston came against the cylinder head of the lower limit of travel, there being a similar bumper of rubber fastened in the recess in the hub of piston on that side. Of course, these cylinder heads had to be strongly re-enforced to withstand the strain, and this was found to answer all requirements, for it would always operate, regardless of whether the limit valve or buttons of the operating cable gave out or not.

In the case of the vertical hydraulics, which were known as the standard elevator, an appliance of this kind was not so easily put on, in fact none was ever devised that acted successfully. The only places they could be used was at the upper end of the run and at the lower end, between the cylinder and operating valve, and this had the disadvantage previously described as existing with the earliest form of limit valve on the horizontal machine. If the valve in the circulating pipe was closed it prevented the elevator from running in either direction; hence, it had to be set so that it would not close entirely, and this very fact impaired its usefulness and effectiveness. In the case of the vertical plunger, however, it was very easily arranged, the cylinder being made so that when the plunger got a little below its lower limit of travel it was made to rest upon the bottom head of the cylinder, and fastened around its lower end was a ring which, when it reached its upper limit of travel, would come in contact with the bottom end of the stuffing box, thereby preventing its ever coming entirely out.

ELECTRIC ELEVATORS

The most popular form of elevator in use to-day is that operated by electricity, and the general arrangement of machines now

in use is that of a worm and gear wheel actuated by an electric motor, the gear wheel being attached to a winding drum or spool, the whole machine, of course, being bolted to an appropriate bed plate, and the worm shaft fitted with the proper form of braking apparatus for use in stopping.

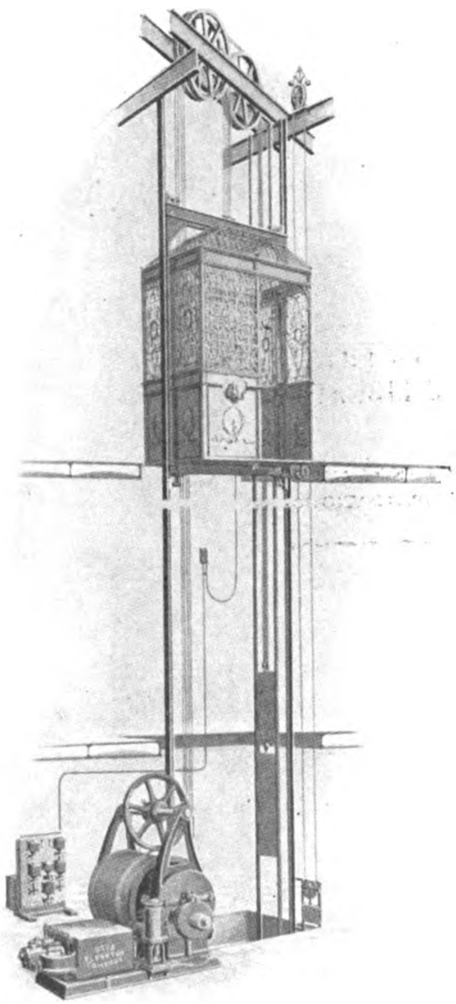
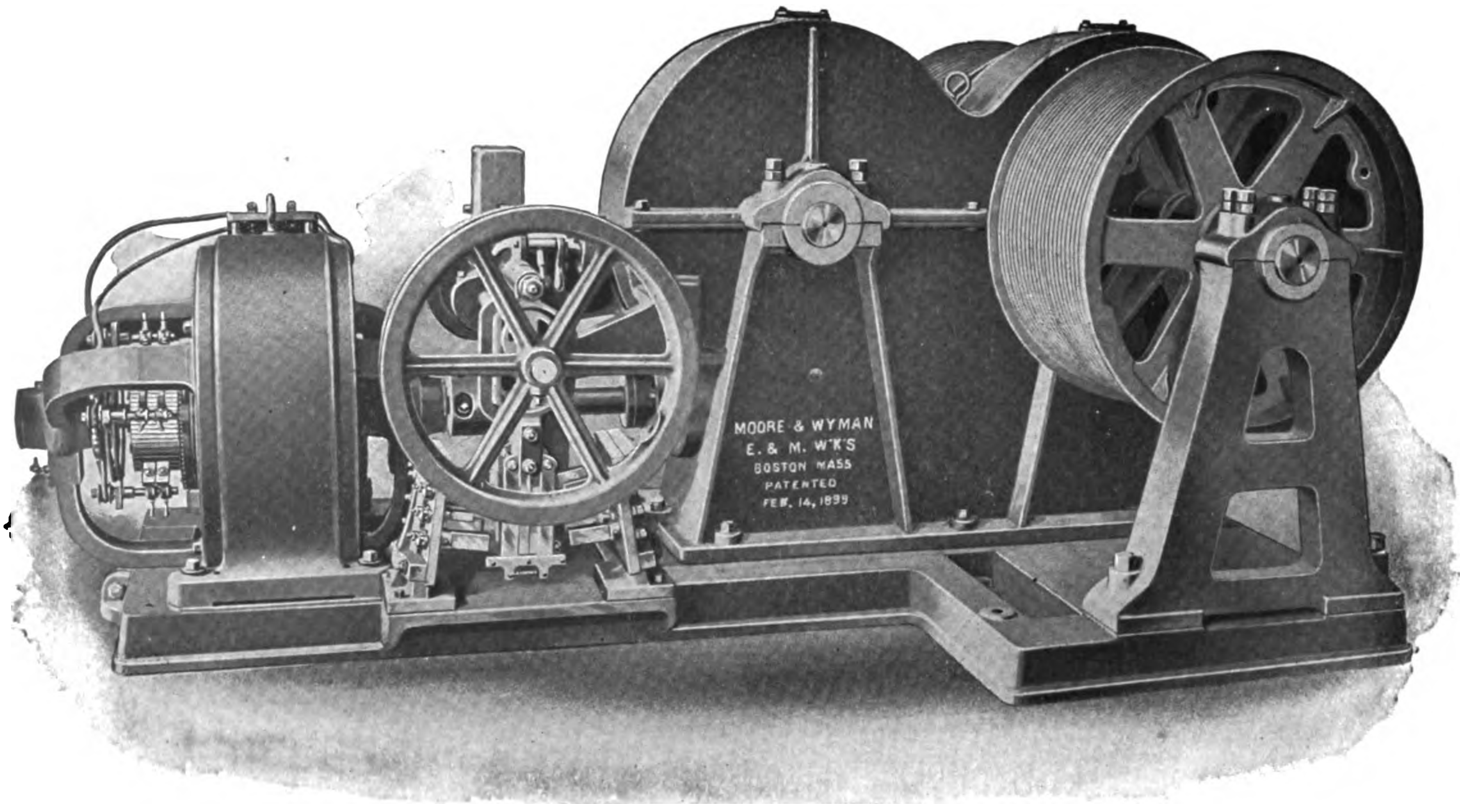


Fig. 11. Electric Elevator.

The motor used for operating an elevator has to differ somewhat from one used in driving ordinary machinery, in that it has to start up from a state of rest with the load on it, and it is a well-known fact that ordinary shunt-wound motors are very weak at starting, hence a modification became necessary. This was discovered very early in the introduction of the electric elevator.

To overcome this difficulty a very strong series field winding is used, and this is usually arranged in two or three sections, and it should furnish fully 30 or 40 per cent of the field excitation. The shunt winding is made proportional to the entire strength of the motor, and when the motor is started, both series and shunt field windings are actuated, and as fast as the motor picks up



STANDARD ELEVATOR MOTOR. DIRECT-CONNECTED.

Holtzer-Cabot Electric Company.

sufficient speed, one section after another of the series winding is cut out, leaving the motor entirely on the shunt winding when it has attained normal speed. By this means a regular speed under any load is obtained, the series winding being used simply to give the necessary torque for starting.

The reason the series winding is cut out when the motor attains normal speed is that if left in action the speed of the motor

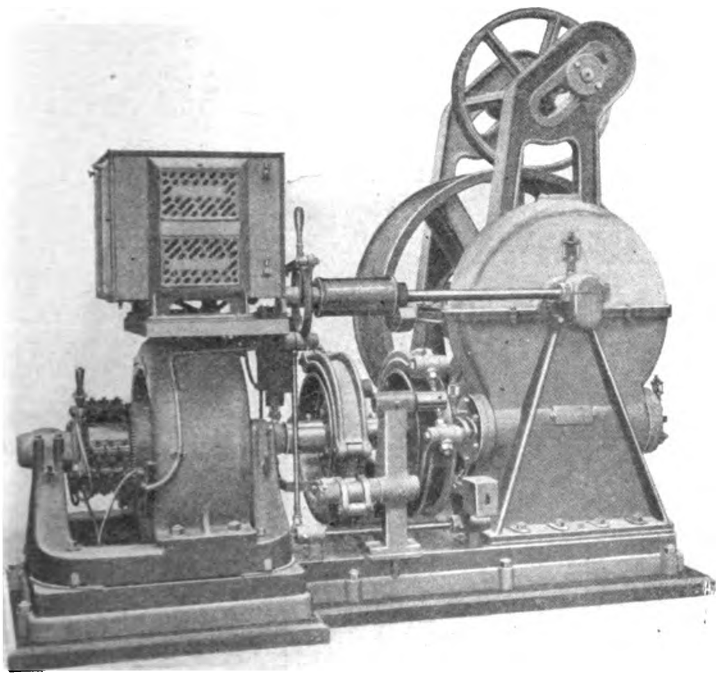


Fig. 12. Direct Connected Electric Winding Engine.

would vary with the load, and this would be more noticeable during a descent of the load than when lifting, for it would accelerate the descent at a rate that would be constantly increasing until the end of the run. By cutting out the series winding and allowing the motor to run on the shunt only, this is avoided. These conditions are brought about by means of the controller.

The offices of the controller are varied. It has first to turn the current into the motor through a certain amount of resistance; second, to gradually cut this out in steps as the motor increases

in speed. At the same time it must gradually cut out the series winding in sections, and when the elevator is lowering, it also has to take care of the short circuiting of the armature, which will be explained later on. It consists usually of a switch for cutting out or breaking the circuit and for closing it, making suitable connections to the armature leads to cause the motor to run in the direction required. This switch is so arranged that when the circuit is closed, it releases an arm or a cross-head that drops by gravity and thereby cuts out the resistance in steps, doing it by moving the contact piece over a number of plates; the speed of its descent is governed by the escape of air from a dashpot. In some cases, instead of releasing the arm described above, it actu-

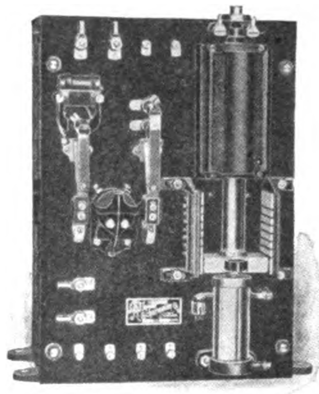


Fig. 13. Controller for Mechanial Operation.

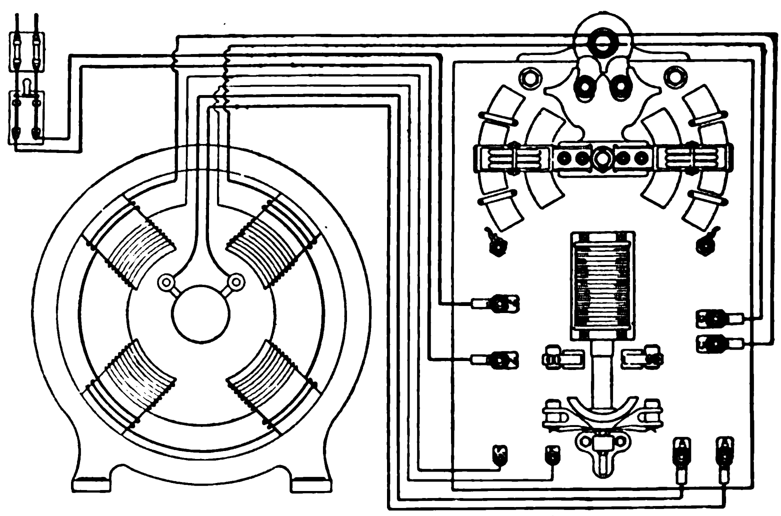


Fig. 14. (A) Wiring Diagram for Mechanical Controller.

ates a solenoid which lifts the arm or cross-head, its speed being governed in the same manner by the use of a dashpot. The breaking of the motor and solenoid circuit is done simultaneously just

prior to the stopping of the elevator, and where the speed of the elevator, or the weight of the loads it carries make it desirable, the controller is so constructed that when the line circuit is broken for stopping, while the elevator is lowering, it cuts in a certain amount of resistance with the armature, causing the E.M.-F. in the armature to pass through this resistance, thereby retarding the speed of the motor. This E. M. F. becomes weaker as the speed of the armature decreases, until it finally ceases with the motion of the motor. This method of bringing the elevator motor to a standstill is used in all standard makes of electric elevators to-day, and has been in use since about 1895. In addition to this, a mechanical brake, operated from the rock-shaft of the machine itself, and also a separate mechanical brake, operated electrically by a solenoid, are used. In the case of the latter, the solenoid is so arranged that it releases the brake when the circuit is closed.

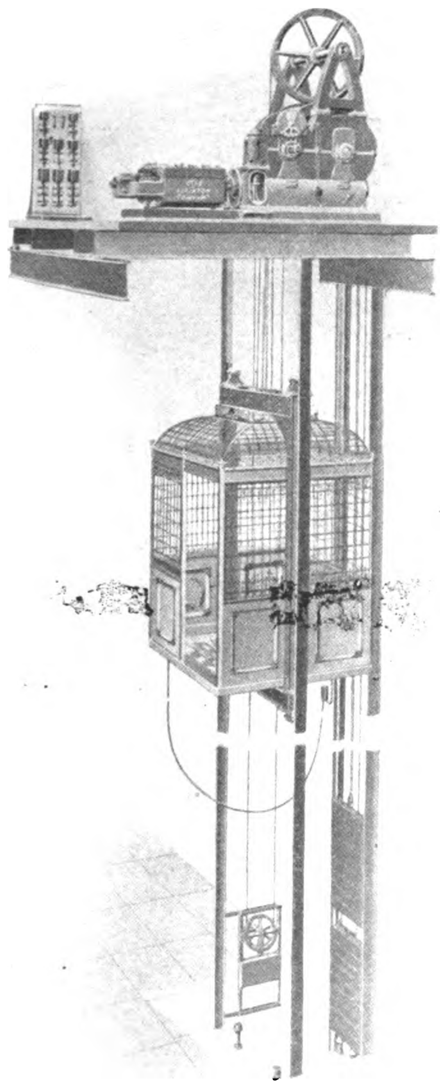


Fig. 15. Electric Elevator with Overhead Driving Mechanism.

This method of stopping and starting, just described, is the one generally used with a mechanical arrangement for operating the elevator; that is to say, with a hand cable or a lever-operating

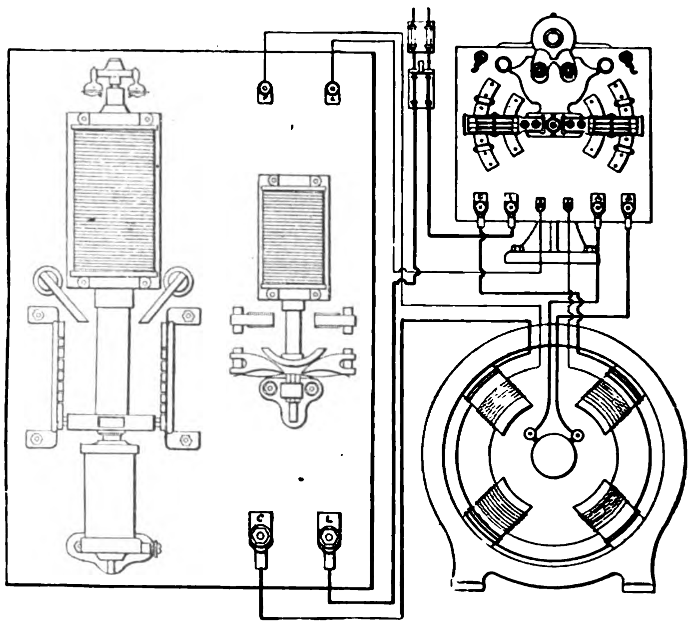


Fig. 16. (B) Wiring Diagram of Controller with Separate Switch.

device; the cutting out of the resistance upon the starting of the elevator is purely mechanical. The arm or cross head on the controller, which cuts out the resistance in steps, is made to move over the contact pieces arranged for this purpose, either by gravity or by a solenoid which moves the arm or cross head; for these controllers are made both ways. Some have an arm working at one end upon a pivot, the other end carrying the carbons over the contact pieces; other types have a cross head which ascends or descends according as gravity or the solenoid comes into action. The cross head always has two sets of contacts.

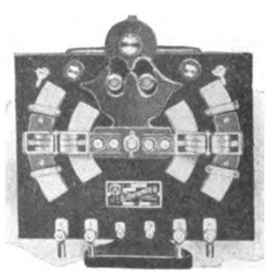


Fig. 17. Circuit Closing Switch.

The time of movement of the arm or cross-head, as the case

may be, is governed by the use of a dashpot. The earlier forms of dashpots were filled with a light oil which would flow freely, and the movement of the plunger in the dashpot caused the oil to flow from one end of the cylinder to the other, through a very small opening, which was adjustable as to size. The time in which the arm or cross head passed over the contact plates was thus regulated, but it was found that the oil was affected by temperature, very cold weather making it sluggish and thick, and the action of the arm or cross head correspondingly slow. Sometimes where the oil was of a volatile nature, considerable waste would occur from this and other causes, and then upon closing the circuit the plunger would move very rapidly until it struck the oil and was brought up with quite a shock, and resistance was cut out quickly for two or three steps. This had a bad effect. Sometimes too, the attendant would neglect to replenish the dashpot at all and it would become entirely empty; then the resistance would be cut out so suddenly as to endanger the safety of the motor. To remedy this a dashpot of somewhat larger diameter was used, having a nicely fitting piston, and the air in the dashpot was imprisoned, being allowed to escape through a minute hole at the top or bottom, according to the way the dashpot was placed. The opening being adjustable by means of a screw, the arm or cross head could be made to pass over the contact pieces at any speed desired, the usual time allowed from closing the circuit to attaining full speed being from four to five seconds.

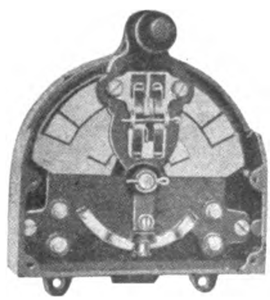


Fig. 18. Electric Operating Switch for Car.

With elevators running at a high rate of speed, however, say 300 feet per minute or more, this method of operation was not as perfect as could be desired; hence, there was devised what is called the electric control. This consists of a small switch located in the cab. From it wires are run in the form of the flexible cable to a point midway of the run of elevator, where the end of the cable is attached to the wall of the shaft, and from that point wires are run to the controller. This cable has to convey but a very small amount of current, simply sufficient to actuate one or more solen-

oids on the controller. These solenoids operate the switches which make and break the circuit in either direction. The throwing of this switch in the cab to the upright or central position, breaks the circuit always, and moving it either to the right hand or left will close the appropriate switch on the controller to run in the direction desired. This is done by actuating a solenoid on the controller, as before stated, which closes the switch to run the motor in the direction desired. The cable attached to this switch has to have at least three wires, one for the line, and the other two for their respective solenoids, but usually the cables are put in with a number of wires, so that if anything happens to any one of those in use, one of the dead wires can immediately be connected, and thus the necessity for replacing the entire cable is obviated.

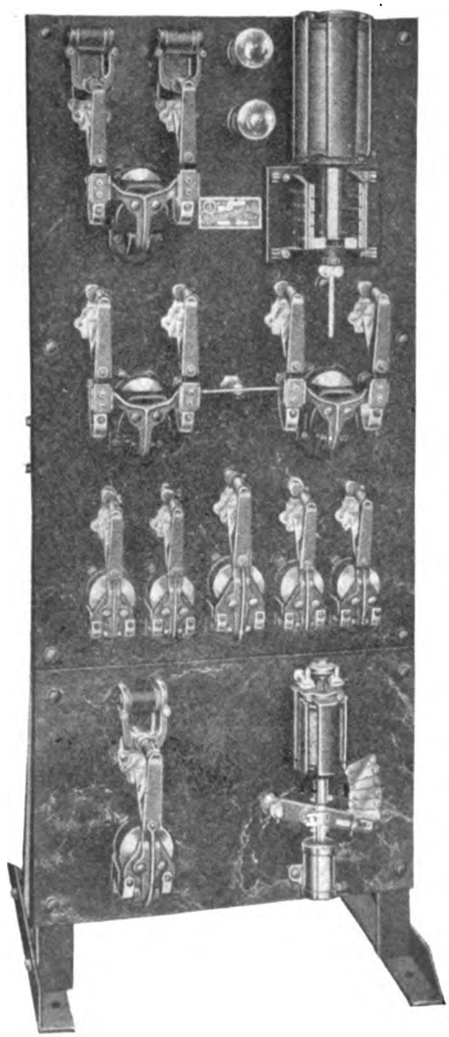


Fig. 19. Electrically Operated Controller.

Controllers of this description operate in various ways; in some, as soon as the line circuit is closed, a solenoid is actuated, which cuts out the resistance in the same manner as described as being used for the lever or hand-cable control. Another form of controller does it in a different manner, which will be described.

The armature is connected with a number of solenoids, each connected with a separate step of the resistance, and so arranged that they require varying amounts of current to actuate them, and the E.M.F. in the armature actuates these solenoids in rotation, the motor being started up at first and running slowly, the E.M.F. in the armature is weak and actuates only the first solenoid, which then cuts out the first step of the resistance. As the speed increases, the E.M.F. becomes stronger and successively cuts, out through the other solenoids, all the resistances as the motor attains full speed. When the circuit is open for stopping the elevator, these solenoids all drop back to their original position and are ready for the next start, and they are used to cut out the resistances in either direction of the motor.

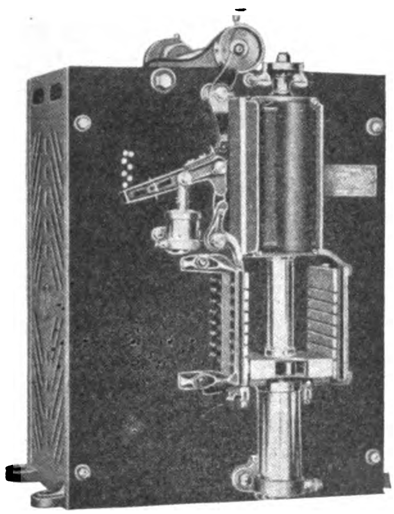


Fig. 20. Mechanical Controller, Variable Speed.

The E.M.F., as before stated, is frequently used as a means of retarding the motion of the elevator when a stop is desired, the most effective method being to introduce a set of resistances in the controller specially designed for the purpose. It is arranged on some elevators so that the E.M.F. actuates a solenoid which applies the brake, the latter being held off by a strong spiral spring. When the circuit is broken, the same movement that opens the switch, connects the armature with this solenoid, and if the elevator is running very fast, the E.M.F. being strong, applies the brake very hard. As the current in the armature, owing to the slowing down of the motor on the application of the brake, becomes weaker, the pressure on the brake becomes less, until finally it ceases entirely, and at this point the other mechanical brake operated by a solenoid, whose office is only to release it, is applied permanently by mechanical means. With this arrangement, one solenoid slows the motor and brings it to a stop, and having attained that point,

the other solenoid releases its hold on the brake and allows the spring to apply it.

This latter arrangement, however, of using the E.M.F. to apply the brake, is simply a roundabout way of reaching the result—partly by mechanical and partly by electrical means—and is not really necessary; the short circuiting of the armature through resistances in the controller is all that can be desired.

In many elevators where a variable speed is desired, connection is made between the armature and a solenoid connected to a

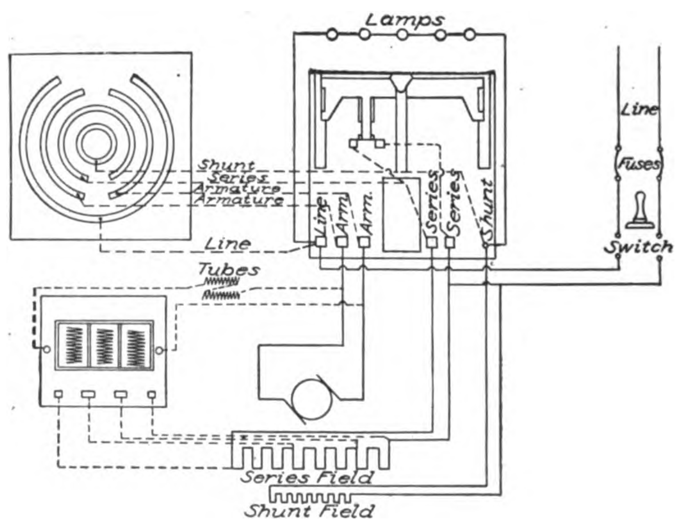


Fig. 21. (C) Wiring Diagram for Mechanical Controller.

switch which is kept closed except when the solenoid is actuated. This switch closes a circuit between the shunt field coils and a bank of resistances in the controller, specially designed for the purpose, and has the effect of weakening the fields. This causes the motor to run at a greater than its normal speed, so that with a light load where the E.M.F. in the armature is not great, the elevator will always start up and run much faster than when a full load, or one nearly approaching it, is in the cage; for when the greater load has to be lifted, the E.M.F. in the armature becomes strong enough to actuate the solenoid, which opens the switch, thereby cutting out the resistance in the fields and leaving them stronger, and the speed of the motor immediately becomes slower. This is a very

nice device and does its work automatically and is quite reliable.

The idea of weakening or strengthening the fields of a motor to gain or lessen speed is almost as old as the first electric elevators, but where current is taken from a public supply, or where only one elevator is used, it is usually not practicable to deviate from the methods above described. The ideal electric elevator,

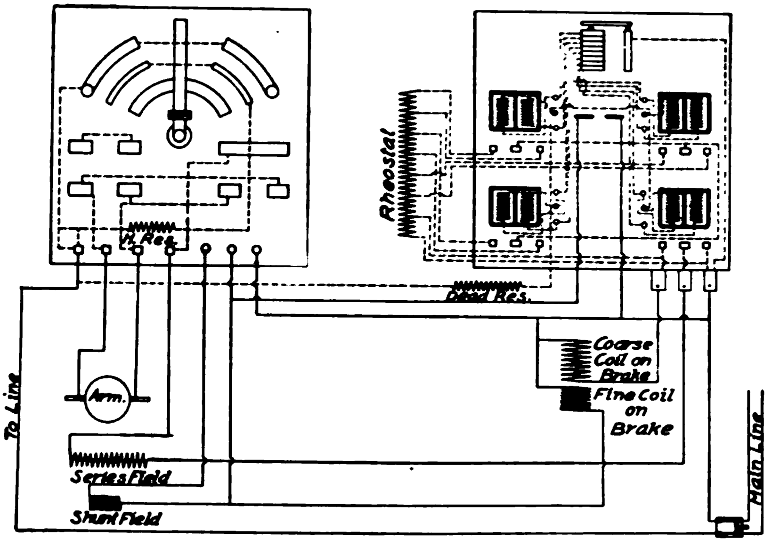


Fig. 22. (D) Wiring Diagram of Controller with Solenoid Cut-outs.

however, is one where a separate dynamo is used for supplying the fields and one for the armature. A field regulator connected with the dynamo supplying the fields can be placed in the cab, by means of which the operator can weaken or strengthen the fields of the dynamo supplying the current to the fields of the armature driving the motor. By this means a great variation in speed may be had. But while fairly economical in its operation, it is a plant that is expensive to install, and though it has been done in a few instances, there are not many of this type of elevator in existence.

ELECTRIC LIMIT SWITCHES

It was found in operating electric elevators that more space was needed between the cab and the overhead sheaves at the upper part of the run, and that a deeper pit was also required at the bottom of the run on account of the occasional slip of the brake.

For frequently, although the mechanical, automatic or limit stop on the machine would break the circuit and apply the brake near the end of the trip, there were cases—for instance when the empty cage was required to ascend at full speed and the brake had become slightly worn and did not grip as firmly as usual—that the cage would go beyond the landing, and the additional space mentioned above was required to prevent a collision. This also happened sometimes at the lower end of the run when an extra heavy load was descending. A lack of care on the part of the operator in breaking the circuit in sufficient time, or the causes just mentioned, would cause the cage to run down to the bottom and bump. To avoid this, as an extra measure of safety, switches are sometimes placed at the extreme limit of the run, the line wire being carried up the hatchway through the switch and returned.

These switches are opened by the car automatically if it should pass a certain point, and the opening of this switch breaks the circuit and at the same time applies an extra strong emergency brake. The switches are operated by means of cams attached to the cage.

MISCELLANEOUS ELECTRIC ELEVATORS

There are one or two other types of elevators that have been more experimental than practical in their nature, which will be mentioned here. One of them, the Pratt-Sprague, consists of a long screw running horizontally in bearings at either end, which is driven directly by a motor placed at one end. The screw runs in a nut having a cross head, which travels on guides horizontally, the same as the cross head of a horizontal hydraulic, and is supplied with sheaves on either end. The construction of the machine is such that a double set of traveling sheaves and also fixed sheaves is necessary. The cables are rove over these sheaves similar to the method described for the horizontal hydraulic, and the motor, of course, is reversible.

One of the principal features of this type of machine was the construction of the nut which traveled on this large screw. It was supplied with steel balls on the pull side of the screw, and they ran close together in single file through a channel, which carried them around through the threads of the nut and caused them to

return to the other end of the same after they had passed through. Of course, there had to be so many of them that they completely filled the channel from one end to the other, and it was thought that their use would reduce the friction to a minimum. It was found, however, in practice that they would get flat spots on them and cease revolving, and where they did this they would cut grooves or scores in the thread of the screw, which latter was a serious matter. They are very prone also to become deranged, and their operation was not as economical as had been anticipated.

Very few of these elevators are in use at the present time. The controlling device, however, was quite novel and the operation of the cage very agreeable and pleasant. The control of the motor driving this screw was effected by means of a small pilot motor operated in turn by means of push buttons in the cage.

Another type of elevator was that devised by Mr. Fraser, of California, the driving mechanism of which consisted of two motors set one above the other. They were necessarily slow speed motors, and each one had upon the armature shaft sheaves of about 20 inches diameter. The motors themselves ran at a speed of about 420 r.p.m., and the cables were so arranged as to form a double bight or loop below, in each of which one of these pulleys on the armature shaft ran as shown in the accompanying illustration. The upper ropes of the cables had sheaves carrying them and running in a frame, to one of which was attached the car cable, and to the other the counterpoise cables. These motors ran in opposite directions, and in the cab were placed rheostats for weakening or strengthening the fields. By this means the speeds

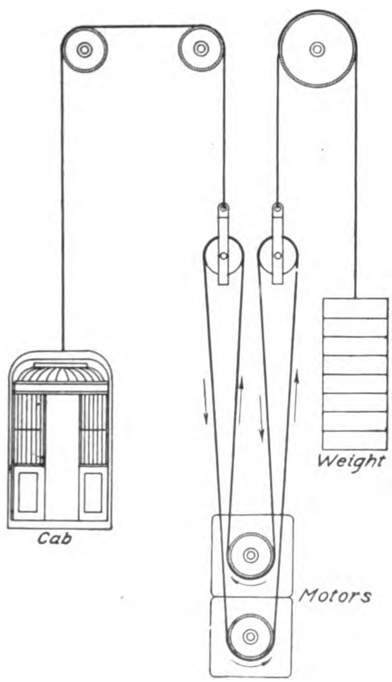


Fig. 23. Diagram of Fraser Elevator.

of the motors could be varied. By reference to the diagram illustrating this description, it can readily be seen that when both motors were running at the same speed, no motion of the car was obtained, but by varying the speed of either motor the car would run at a speed equal to half the difference of the two motors. No reversing apparatus was needed with these motors; they ran continuously in one direction, the motion of the car being gotten entirely by the change in speed, and the most desirable stops and starts were obtained. But the machine was very severe on the cables, so destructive in fact that they had to be renewed frequently; and taking it altogether, it was not found as desirable a machine as had been anticipated, either from the point of economy or maintenance, but results in operation were all that could be desired, including the speed attained and smoothness of stops and starts.

ELEVATOR ACCESSORIES

An elevator is really a vertical railway, but differs from one running on horizontal rails in that it does not use wheels, but slides on its track, and in order to avoid friction as much as possible, the cage should be hung centrally. The rails used for the cage to travel on are, in the more common types, usually of wood, hard maple being the material mostly adopted, and it is kept constantly lubricated with some form of grease. The guide ways after some weeks' use become rough and dry from various causes, principally from the rubbing off or evaporation of some of the component parts of the grease, and also from the accumulation of dust, which sticks readily to the lubricant. They then have to be cleaned off and relubricated, the object being of course to keep them as smooth and free from friction as possible.

Great care has to be taken when installing them to have them in perfect alignment and the joints very even; and maple, being a wood that is prone to warp, has to be put on in short pieces, the usual lengths being about four feet. The ends of these guides are tongued and grooved to fit into one another, and where the guide posts, to which they are attached, are made of wood, they are fastened thereto by means of appropriate lag screws, the ends of which are recessed into the face of the guides. The shoes on the cage

which run on these guides are usually machined to fit, and are made as smooth as possible at their faces of contact.

The device generally used for stopping the cage in case of a sudden descent, caused either by the breakage of the cables to which the car is suspended or by the derangement of any part of the machinery, is a pair of dogs, one placed in each guide-shoe beneath the car on opposite sides. These dogs are in the form of an eccentric, the outer face of which is supplied with coarse teeth, which, when the dog is revolved on its axis, come in contact with the guide strips; and as these teeth enter it, the descent of the car causes a further partial revolution of the dogs, so that the guides become tighter and tighter as the car descends, and bring it to a stop. This operation takes much less time to occur than it does to describe it here, the fact being that after the dogs begin to catch, the car descends but a very few inches before it is brought to a dead stop.

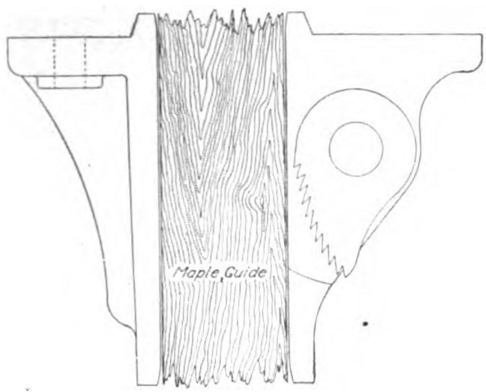


Fig. 24. Eccentric Safety Dog.

These dogs were originally used in connection with a spring for throwing them; hence when they acted at all they acted very quickly and before the platform had gained much headway, and while this was quite satisfactory in a slow running elevator, it was found to be quite objectionable with elevators of high speed—the sudden stopping producing a severe shock to the occupants of the cage—and moreover there were many cases where the elevator would descend rapidly, and the dogs failed to act, because they depended on the severing of the hoist cables for their action. They were operated by a spring which, being held in tension by the weight of the cage on the hoisting cable, would never act while that tension existed. Hence, if the cables were to break at or near the drum of the machine—the machine being located in the basement—these cables had to pass from the drum up and over sheaves at

the top of the hatchway and it would require considerable power to drag them over these sheaves. This would be sufficient in itself to hold the spring out of action.

With the introduction of the safety governor, however, this trouble disappeared. The governor is a revolving sheave having within its rim dogs or arms set upon pivots and held in place by means of strong springs, either spiral or flat. These springs are

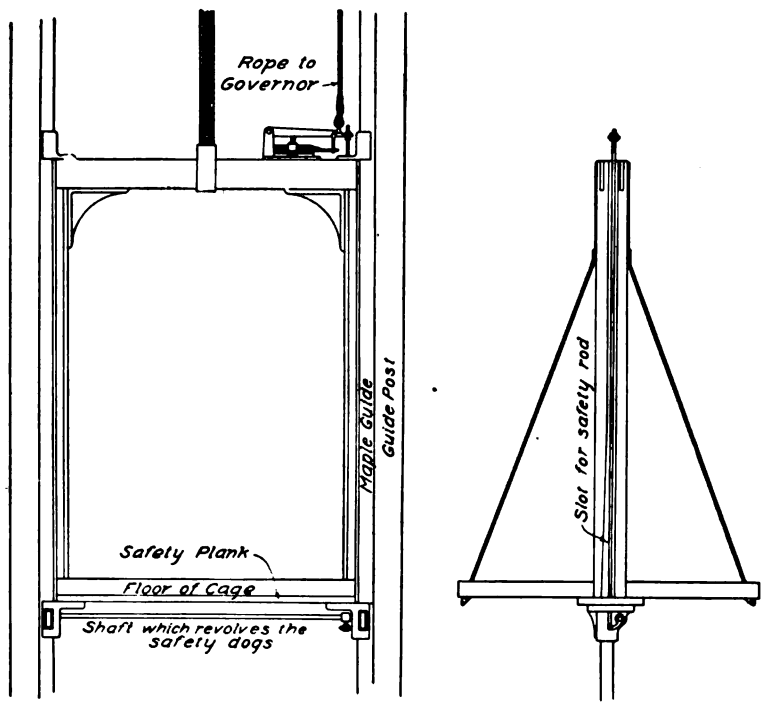


Fig. 25. Arrangement for Throwing Safety Dogs.

so adjusted that the normal speed of the elevator does not affect either them or the dogs, but should the speed of the elevator exceed the normal by about 25 per cent, the centrifugal force exerted by these dogs, which are weighted somewhat, will overcome the tension of the springs, and they will fly out beyond the rim of the sheave, catching on a stand in which the sheave runs and stopping its revolutions entirely.

Now this sheave has a V-shaped groove in which runs a manila rope about $\frac{3}{4}$ inch in diameter. One end of this rope is

made fast to a lever on the top of the cage, which operates the safety dogs, the other end is carried down the hatchway and around another sheave at the bottom and back again up to the cage, where it is attached at some convenient point, usually to an arm placed on the stile for that purpose. This sheave, which runs in the bight of the governor rope, is in a frame, which runs on guides

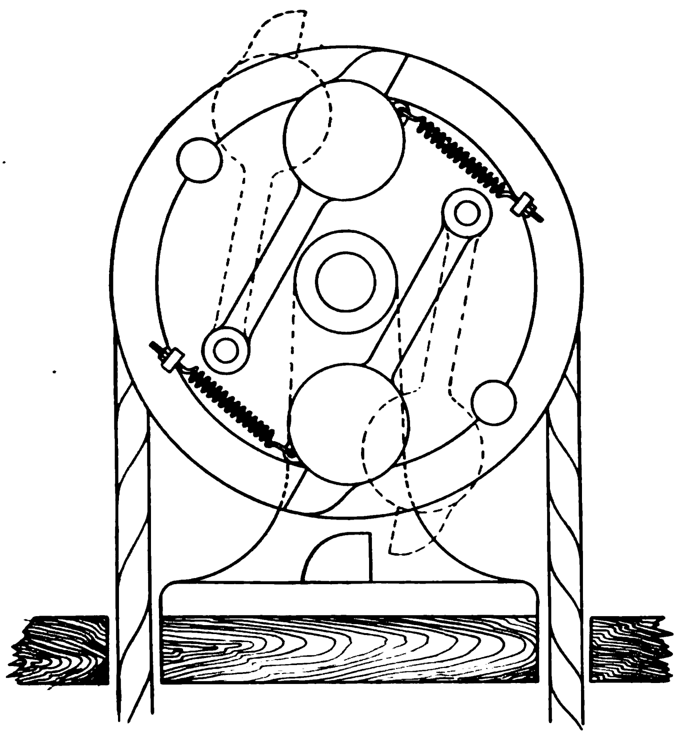


Fig. 26. Diagram of Safety Governor.

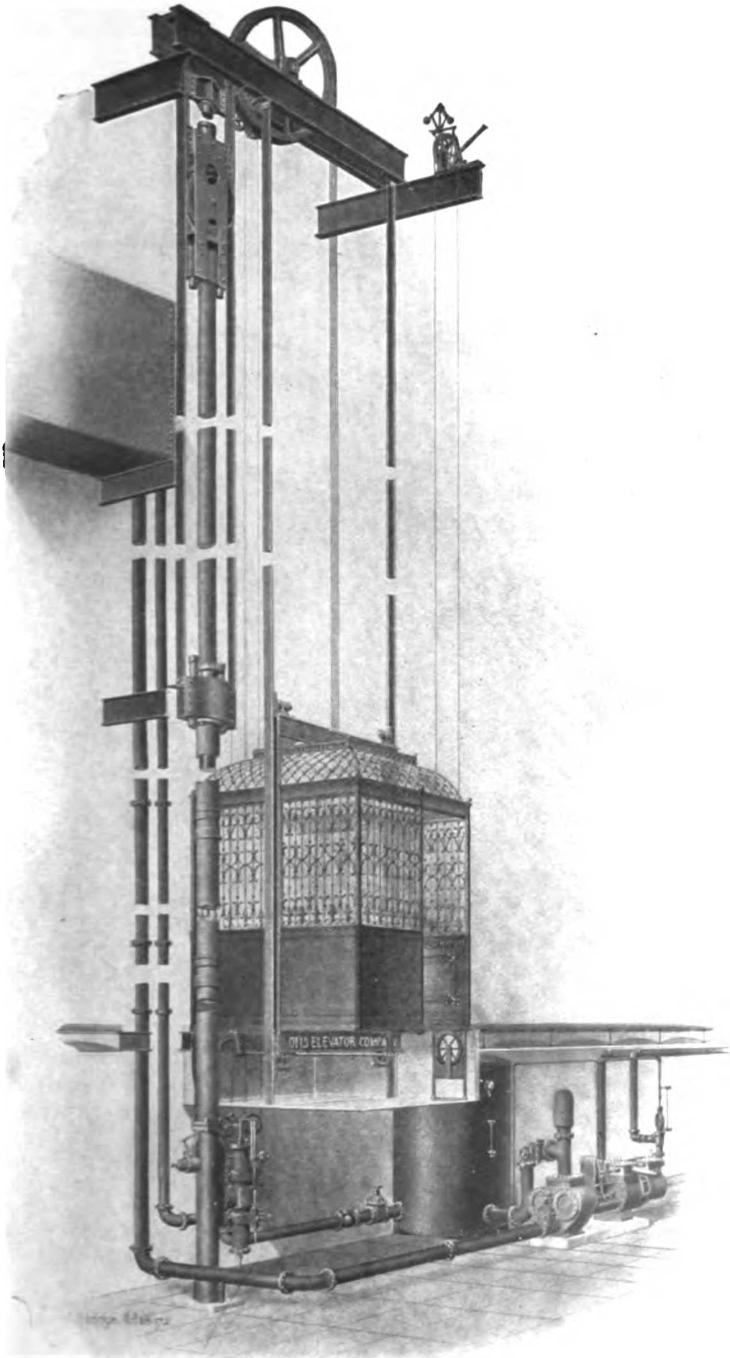
and has a moderately heavy weight attached below it which serves the double purpose of keeping the governor rope taut and of taking up or compensating for the stretch of the rope. It also gives the necessary tension for driving the governor, and when the sheave in its revolutions throws out the dogs and stops itself, as before described, the V groove in the sheave grips the governor rope tightly and thereby pulls on the safety lever on the cage and throws in the safety dogs. It can be readily seen that with an appliance of this kind, the cage would have to descend quite a

distance before its speed would increase sufficiently beyond the normal to actuate the governor, and for this reason the style of safety dog described above, which was the first form introduced, was very objectionable, on account of its sudden stopping of the cage at the high speed it had attained by the time the dogs were thrown in. Therefore a modification of it was introduced in the form of a chisel, which, instead of catching into the guide strip as suddenly as the eccentric dog, would plane it out for quite a length, only entering deeper after the car had descended some little distance and thereby bringing the cage to a more gradual stop.

The form of safety governor described above is the one now in general use; the earliest form, however, differed slightly from it, being a governor having arms with balls on the ends, and revolving horizontally. The same method of driving it, however, was used, except that this governor was placed on the cross beam of the cage and threw the safety directly itself.

A still earlier form of this type of governor was used at the top of the hatchway, many years ago, but not driven by a rope. In the case here referred to, drums were used at the top of the hatchway, and separate cables from the hoisting engine were run directly to the drum overhead, terminating there. Other cables were run from that drum down to the cage, so that there was a constant winding of one set of cables on the drum and unwinding of the others, according to the direction the elevator was going. This drum had on its axis a gear wheel, which drove the governor, and the governor, in that case released a very heavy weight placed on the end of the lever. The dropping of the weight applied a powerful brake to the rim of the drum. This style of governor is not much used at the present time.

With the introduction of higher speeds in elevators a guide post and guide combined in one, and made entirely of steel, was devised and used, and it is in use to-day with all the high-class elevators; but its introduction, while giving greater smoothness of operation and offering many advantages that the wooden guide did not possess (that of remaining in alignment and consequently giving smoother action being the principal one), caused the necessity for a different form of safety than the eccentric or chisel dogs,



PULLING PLUNGER HYDRAULIC PASSENGER ELEVATOR.

before described, which were not applicable to this form of guide, hence a new device had to be introduced. This was in the form of a powerful pair of nippers placed below the car, one on each side. The inner ends of these nippers on being forced outward,

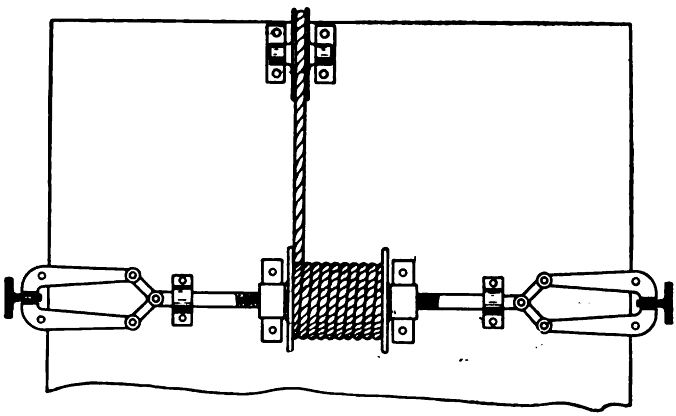


Fig. 27. Safeties for Steel Guides.

caused the jaws of same to grip the steel guides with tremendous force, but the means of applying them being gradual they did not stop the cage suddenly but allowed it to slide several feet, bringing it gradually to a stand.

The form of governor used to actuate these safeties is similar to that described above. The pulling of the governor rope causes the release of a very powerful coil spring under the car, which forces the dogs into action. There are several forms of this device, none of them differing materially, except in the method of applying the power to grip the guides, one or two of them dispensing with the coil spring, before mentioned, and using a powerful screw and knee joint. The screw is operated by the end of the governor rope, which is coiled several times around a spool or barrel on the body of the screw. The governor rope is gripped by the governor, and the descent of the car uncoils the governor rope off the spool, which is made to revolve, and, being attached to the screw, causes it to revolve. This action causes the knee joints to force the long end of the nippers apart, the short ends gripping the guides powerfully.

Another point in which the elevator differs from the horizon-

tal railway is that in moving a load on an elevator the force of gravity has to be overcome as well as that of inertia. Hence, it is found to be economical to counterbalance the cage, and for that reason slides very similar to those on which the cage travels, but lighter in construction, have to be provided, in which a counterpoise weight travels. Sometimes more than one of these counterbalance weights are used, in some cases running in separate slides, in others, varying with the conditions, with each weight having a slide to itself.

When a counterbalance weight is used, which is attached directly to the cage, it can never be as heavy as the empty cage by several hundred pounds, depending largely upon the height of the building and the number of cables attached, for when the cage is at the top of the run, these cables hang over on the opposite side of the sheaves and have the effect of further counterbalancing the cage. The weight of the cage itself must therefore be greater than the combined weight of these cables and the counterbalance weight, otherwise, the cage would not descend when empty. When it becomes necessary to have the counterbalance weight fully as heavy as the empty cage, or, as occurs in many instances, it is required to be greater than the cage, this counterbalance weight has to be attached by means of cables running over sheaves at the top of hatchway to the opposite or back side of the hoisting drum. Where a cage is large and consequently quite heavy, the attaching of a counterpoise to the cage itself, as well as to the rear side of the hoisting drums, is done as a means of relieving the hoisting cables of a part of the weight they have to carry, and this adds to their durability and safety.

In the case of the electric elevator the over-counterbalancing of the cage is found to be quite economical in this way. An estimate is made of the average load which the elevator has to lift in its daily service, and it is over-counterbalanced to about this amount, the result being that, with the average load, the only power to be exerted in moving it will be that necessary on account of the friction of the machinery. For instance, it may be estimated that the average load of the elevator will be 500 or 600 pounds, although it is built to lift say 2,000 pounds. If it is overweighted

this amount, it will be on a balance with the average load, and the amount of power required to move it will be a minimum.

This arrangement is found to give very good results as to economy in operation, but of course in order to get the very best results the cage should be built as light as possible commensurate with the requisite strength and stability; for if the cage is made unnecessarily heavy and it has to be counterbalanced equivalent to its weight, there is that much heavier body of material to start and stop each time the elevator is operated, and there is that much greater inertia to overcome, which consumes power. The necessity, therefore, of building everything as light as possible will be readily seen.

Where two counterbalance weights are used running in one slide, it should be an invariable rule to place the heavier weight, which is always that one attached to the rear side of hoisting drum, below the one attached directly to the cage, for there is a liability at times of counterbalance weight cables breaking, the same as there is with hoisting cables. Should this occur with the drum or heavier weight above the cage weight, the consequences would be disastrous, for combined they would weigh considerably more than the cage, and in falling would rush it upwards to the top of the hatchway at a great speed, provided of course that the cables by which the car weight was attached did not give way. Where the cables of the lower weight pass the upper weight, the latter is usually slotted throughout its whole length to allow their passage.

The best form of counterbalance weights used at the present time in elevators is made in sections so as to be readily changed or adjusted when desired. They consist of a head and bottom weight, which are usually provided with suitable guide shoes to run on the slides, and between them are shorter weights, which do not touch the guide, and which are called subweights. The whole number of weights are held together by means of strong iron rods with double nuts at either end. These pass through holes cast in the upper and lower sections of the weight, and the intermediate or subweights are held in position on these rods by means of grooves in their ends, which fit over the rods, the whole being clamped together firmly by means of the nuts just mentioned.

Sometimes, where the counterbalance weight is necessarily very long, a middle weight with guides on it is inserted, through which the rods holding in the subweights pass, thus giving it greater rigidity and safety.

A very important part of the elevator is the overhead sheaves and bearings. In the earlier forms of elevators, these bearings were set on wooden beams overhead, passing across the hatchway in the proper direction to let the cables drop where required. In later years, however, general practice seems to lean to the use of steel I-beams for this purpose, and they are certainly much safer in case of a fire occurring in the building. It frequently happens in case of a fire that the elevator is one of the principal means for getting people out of the building, and where these beams are of steel there is no doubt as to their greater safety under such conditions. The sheaves should always be as large as can possibly be used under the circumstances,—never less in diameter than the drum around which the cables wind—and the rule usually adopted is that the sheave should be at least 40 times the diameter of the cable which is to run over it, and as much larger than that as the conditions will permit. It is also very important that the score of these sheaves should fit the cable very well, otherwise, with heavy loads the latter becomes distorted, and even under the best conditions the wear of the cable will be rapid unless lubricated. For this purpose, there is nothing better than raw linseed oil applied with a brush, and it is very much improved in usefulness if a small quantity of the finer quality of plumbago be mixed with it. This material when unrefined is full of grit, and is put on the market in this condition for use as facing for moldings in foundries. It is very essential that this kind be not used, for the presence of the grit will have exactly the oppposite effect to that intended. After the plumbago has been carefully freed of all the grit it contains, it is a very good lubricant and in this condition it is very serviceable, both for the purpose just described and, in connection with grease, for the slides.

CABLES

Should the wires of the cables used in hoisting be run perfectly parallel to one another, they would not only last longer but

they could be subjected with safety to a much greater strain, but that is found to be impracticable with running ropes, hence they have to be twisted, first in strands of 19 wires each, then six of these strands are twisted together around a center or heart made of hemp. The object of this arrangement is that in working over the sheaves the wires may rub on something softer than themselves and not abraid, for the parts of a hoisting cable when in use undergo many changes in position. For instance, when passing up the hatchway, the parts remain normal or as they were when made up, but when they come to the sheave the strands necessarily change positions slightly, being bent in a circle, and after passing over the sheave and down on the other side they change again to nearly the original position. As they are twisted around one another, different parts of the same cable change their relative positions quite frequently, for their very shape—being spirally wound around one another—causes them to roll slightly in the grooves of the sheave, and they do not always fall into exactly the same position when they return. Hence, the absolute necessity for some sort of lubrication. This change of position or twisting of the cables has made it advisable in cases where a large number of cables are used together (say for instance four or six cables running over one sheave) to use them alternately of right and left hand lay, the meaning of which is that some cables are twisted right-handed and others left-handed, and by using them alternately in this way they serve to correct the action of each other and prevent many minor troubles that will occur when laid up alike.

The scope of this article will not permit going into details relative to the proper fastening of the cables, which is a very important feature, but which is really in the hands of the elevator constructor, and with which the attendant has little to do.

The journals of the gudgeons or shafts upon which the sheaves revolve should always be of soft strong steel and of ample diameter, and the boxes in which they run should be lined with a very good quality of babbitt, and should be provided with good lubricating facilities. They are parts of the elevator that are neglected perhaps more than any other. Being at the highest point and out of the way, they are very seldom noticed, but at the

same time too much emphasis cannot be placed upon the absolute necessity for properly attending to this important feature of the machine.

The operating cable, owing to the impossibility of following the rule laid down for the hoist cables regarding the diameters of sheaves, is usual to make of a much finer wire, and the number of wires to a strand is also greater. It is usually that kind of wire rope which is termed tiller rope, and is soft and flexible. The diameter is almost invariably $\frac{1}{2}$ inch, except in cases where the lever device is used, when the necessity for a rope of that size does not exist. The $\frac{1}{2}$-inch diameter is used principally because it is convenient for the hand, and it is seldom that a larger sheave than 12 inches is found practicable, but in any case, whether for hand cables or hoisting cables, iron ropes should always be used. It is true that a steel rope has a greater tensile strength, but the bending over the sheaves causes it to crystallize much more rapidly than an iron rope does, and it will consequently commence to crack sooner. The very best iron for this purpose is either Swedish or charcoal iron, which are very nearly pure, exceedingly ductile, and will stand the bending and straightening for a much greater length of time than a steel rope.

Wire cables have, in some instances, been known to run without fracture for eight, ten, and even twelve years, but there are very few in constant use that last more than three or four years. Some do not last longer than two years where subjected to constant and severe service, and in any case they should, on general principles, even if showing no outward signs of deterioration, be changed for new ones at the end of five years, under the most favorable circumstances. Cracking occurs very gradually and can readily be detected long before it actually occurs by the exterior appearance of the rope, but there are many cases where ropes crack inside before they do on the outside, and this can only be discovered by getting the rope entirely slack and slightly untwisting it so that an examination of the interior can be made. Holding one's hand gently on the rope while it is running will frequently detect a cracked wire if it be on the outside, but an examination of this kind must be carefully made to be of any service.

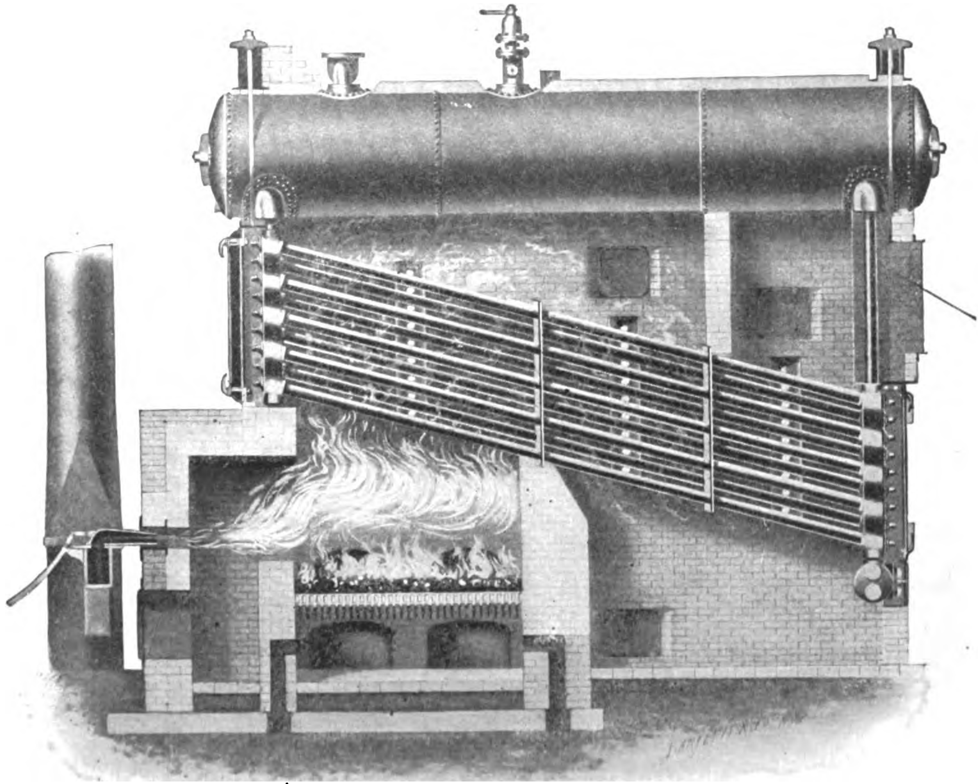
In regard to sheaves, sometimes an arm will crack through an undue shrinkage strain brought about possibly in some cases by disproportion in the design, or by unequal cooling in the foundry. In such cases the crack usually opens quite wide, but where it occurs from undue shock or jar, the fracture may occur and remain closed, so that it is not detected. Still the sheave is unsafe. Usually this can be perceived by care on the part of those in charge, for when the arm containing the fracture is in such a position that it is not subjected to the strain of the cable running over it, the crack, however minute, will open slightly, and it is liable to absorb or take in a minute portion of the oil which is generally on the sheave and which runs down from the journal boxes. This arm when it comes around to that point where it is subjected to compressive strain will force the oil out of the fracture in the form of a small line projecting above the surface of the sheave. It requires a sharp eye to detect this, but it can be seen with care, and many a possible accident has been avoided by the acuteness of the attendant in this respect. It is here mentioned for the benefit of those readers who may be in charge of elevators.

AIR CUSHIONS

About 1878 Mr. Gray, of Cincinnati, conceived the idea of an air cushion as an extra means of safety for elevators, and obtained the first patent for a device of this kind. The air cushion consists of an extension of the hatchway below the lower landing, and is in the form of a strongly enclosed air-tight chamber open only into the hatchway above. The guide posts are run down into this hatchway and the cage is made to fit it rather closely. This is usually done by fastening strips of thick rubber or leather below the floor of the cage, and allowing them to project to within about ½ inch of the sides of the air cushion. Now in case the cage should break loose from the cables, it will descend until, having entered this chamber a certain distance, the air contained within the chamber is compressed sufficiently to resist the further descent of the cage. At this point it begins to escape through the margin left all around the sides and the speed of the cage's descent is retarded until it sinks gradually to the bottom of the chamber without shock or jar.

The margin all around the cage for the escaping of air is a very essential feature to the success of this device. Many errors were made in some of the earlier forms of this device, owing to this feature not being well understood, for it is quite possible, where the air is confined too closely, to stop the cage violently; in fact, this will be the effect if the air is not allowed to escape. On the other hand, if too wide a margin is left, the effect desired will not result. Great care has to be exercised to have the chamber forming the air cushion air tight, strong enough to resist the strains that will be brought to bear upon it, deep enough to enable the car to come to a stop gradually, and to have the air space around the car just right to allow the air to escape in sufficient quantity to prevent a shock, and at the same time not fast enough to allow the car to drop too quickly after it enters.

The usual depth of the air cushion is about 8 or 9 feet and the space or margin left between the cage and sides of air cushion is from $\frac{3}{8}$ to $\frac{1}{2}$ inch. Some modifications are usually made after the work is finished by dropping the cage from a moderate height and noting results, before allowing it to drop the full extent of the run. This is an experiment that should not be performed by inexperienced persons, for accidents have frequently happened even to men thoroughly experienced in the business.



Section of Babcock and Wilcox Boilers Fitted with Kennedy Burners for Burning Blast Furnace Gas.

CONSTRUCTION OF BOILERS.

A steam boiler, or steam generator, consists of a vessel to contain the water and the steam after it is formed; a fire-box to contain the fire; tubes, flues and uptake to transmit heat and conduct the hot gases from the fire to the chimney, and various fittings to facilitate the safe and economical operation. Boilers are often classified according to their uses and conditions; thus we have stationary, marine and locomotive boilers. Boilers having a shell partially filled with tubes, through which the hot gases pass, are called tubular, fire-tube or shell boilers; and those having a large flue in which is placed the fire, are called flue boilers. If the tubes are filled with water and the hot gases are outside, the boiler is called a water-tube boiler.

Steam boilers are made in a variety of shapes, according to the type, uses and conditions. Let us first consider boiler construction in general, leaving out the peculiarities of marine, locomotive and water-tube boilers.

MATERIALS.

The materials of which boilers are constructed are exposed to conditions which weaken them and shorten the life of the boiler. Among these conditions are corrosion, both external and internal, high pressure, and expansion and contraction, due to varying temperature and pressure.

Cast iron was the material of which the earliest forms of boilers were made, but on account of its low tensile strength and its unreliable nature, it is now but little used, except for parts of water-tube boilers, and sometimes for the ends of low-pressure cylindrical boilers and for fittings. It is cheap and resists corrosion but on account of its unreliability and brittleness, the parts must be made thick and therefore heavy.

Wrought iron, up to about 1870, was the principal material used for boiler plates. It is a pure iron prepared from pig iron by a process called puddling, described in "Metallurgy." Wrought iron is well adapted for use in boiler construction, as it is strong, tough and fibrous, and combines high tensile strength with ductility and freedom from brittleness. When the properties mentioned are well combined, wrought iron will resist strains due to unequal expansion. Boiler fastenings, stays and other parts made by welding are sometimes made of wrought iron. It is customary to consider that a bar loses about one-quarter of its strength by welding, although it is often stronger in the weld, owing to the working of the metal during the welding process.

Steel has entirely displaced iron for boiler-shell work. Boiler steel is made by the open-hearth process, and contains for ordinary thickness of 1 or $1\frac{1}{4}$ inches 0.25 per cent carbon, while thinner plates of $\frac{1}{4}$ inch should not contain over 0.15 per cent carbon. Larger percentages of carbon, while accompanied by an increase in tensile strength, lessen the ductility. The following properties show steel to be the best boiler material at present: great tensile strength, ductility, homogeneity, toughness, freedom from blisters and internal unsoundness. Blisters and unsoundness are faults sometimes met with in wrought-iron plates.

Copper in many respects is superior to wrought iron for boiler construction. It is homogeneous, resists oxidation (the corrosive action of most feed waters) and incrustation. It is more ductile and malleable and a better conductor of heat, which not only gives it a higher evaporative power, but also enables it to last longer under the intense heat of the furnace. Its disadvantages are its low tensile strength, about 30,000 pounds per square inch, and its decrease of strength with an increase of temperature. In heating from the freezing point to the boiling point it loses 5 per cent of its strength, and at 550° F. it loses about one-quarter of its strength. For these reasons and on account of its high price, it is now seldom used in boiler work.

Brass is an alloy of copper and zinc in which the proportions of each vary considerably. The red color comes from a larger per cent of copper. Red brass is better and more expensive than yellow brass. Brass is used for valves, gauges and other fittings.

Bronze is an alloy of copper and tin, and is advantageously used for valves and seats of safety valves where the wear is great.

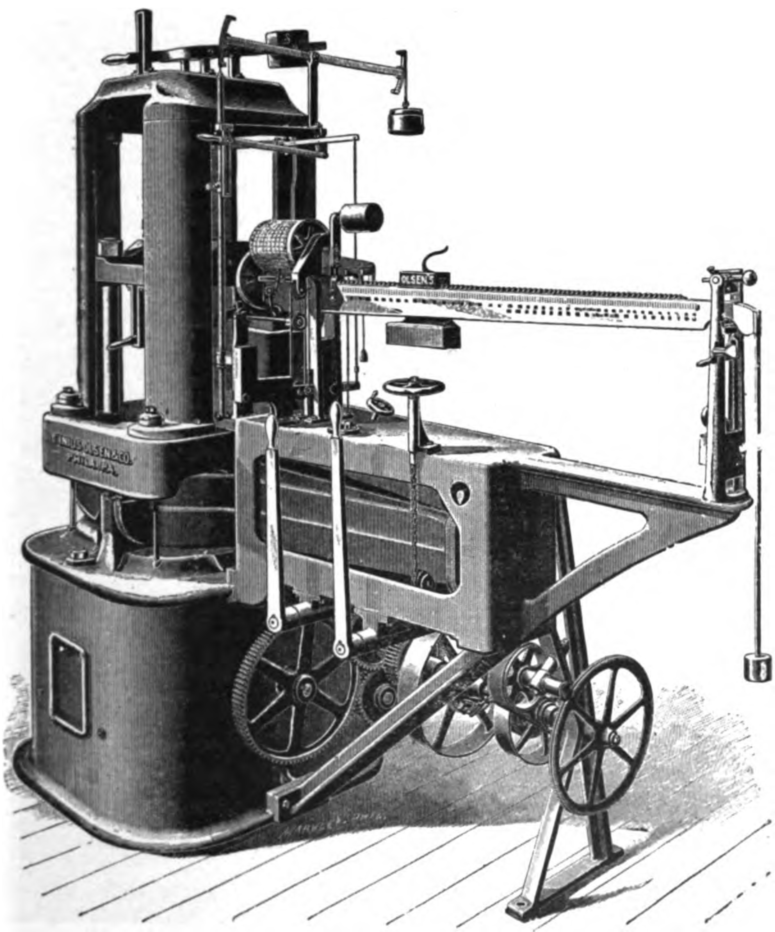


Fig. 1.

TESTING MATERIALS.

In order to determine the strength and the other qualities of the materials, specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined at the same time, testing machines are used. There is a large variety of testing machines, adapted for various materials, but the general principles are the same.

Testing Machines. The testing machine consists of a frame and two heads, to which the ends of the test piece are fastened by wedges or other devices. By means of steam or hydraulic power one head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. In small machines the pull may be applied by a lever.

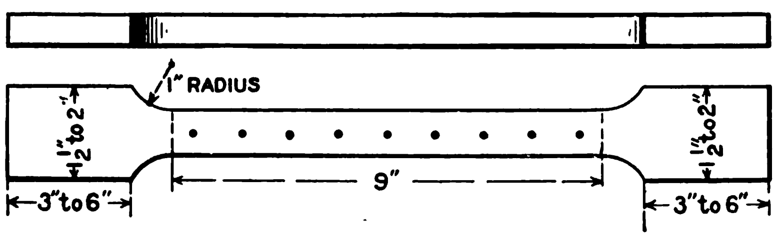


Fig. 2.

Testing machines are made for all varieties of testing: tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 1 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials, test pieces or specimens are prepared. For testing iron plate the test piece should be at least 1 inch wide, about 2 feet long and planed on both edges. Many engineers recommend these dimensions. According to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center.

To ascertain the tensile strength and other qualities of steel, a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 2. The straight part in

the center is 9 inches long and 1 inch wide; and to determine elongation it is marked with light prickpunch marks at distances 1 inch apart, the marked space being 8 inches in length. The ends are $1\frac{1}{2}$ inches to 2 inches broad and 3 inches to 6 inches long.

As has been explained in "Mechanics," the force necessary to break the piece is the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19,200}{.4} = 48,000$ pounds per square inch.

EXAMPLES FOR PRACTICE.

1. If a piece of boiler plate breaks at 33,500 pounds and the reduced section is $1\frac{1}{8}$ inches by $\frac{1}{2}$ inch, what is the ultimate tensile strength?

Ans. 59,555 pounds.

2. A boiler plate is claimed to be of 64,000 pounds tensile strength. If the section is 1 inch wide and .63 inch thick, what should be the reading of the testing machine when the specimen breaks?

Ans. 40,320 pounds.

3. A test piece of the form shown in Fig. 2 measured 8 inches between the prickpunch marks before testing and 9.56 inches after testing. What was the per cent of elongation?

Ans. $19\frac{1}{2}$ per cent.

4. If the area of section before breaking is .4825 square inch and after breaking is .236 square inch, what is the per cent of reduced area?

Ans. 51 per cent.

STRENGTH OF BOILER MATERIALS.

The crushing strength of cast iron is high, varying from 50,000 to 75,000 pounds per square inch; its tensile strength is low, varying with the chemical and physical properties of the iron from about 15,000 to 22,000 pounds per square inch.

Wrought-iron plates having a tensile strength of from 50,000 to 60,000 pounds, with an elongation or ductility of from 20 per cent to 30 per cent, are suitable for boiler work. Boiler iron may be

tested in the following ways if testing machines are not available: Cut from the plate a strip about 2 inches wide and bend it cold, down upon itself; if it shows no fracture on the outside curve, it is satisfactory. This is, however, a severe test, and only the best flange iron will stand it; on the other hand, any iron which, when heated to a cherry red and bent, shows cracks or fracture on the outer curve, is unfit for use in boiler construction. When wrought iron was used for boiler plates it was customary to give the plate what is called the hammer test. The plate was suspended clear of the ground and struck with a hammer at intervals of three or four inches over its surface; a clear, ringing tone indicating a sound plate, while a dull sound indicated with fair certainty a defect such as internal unsoundness.

Mild steel has a tensile strength of from 55,000 to 65,000 pounds per square inch, with an elongation of 25 per cent. A test piece cut from a plate $\frac{3}{4}$ inch thick or less should stand bending double, when hot or cold, and not show any cracks; thicker plates should be capable of being bent at a small radius to a large angle without showing any cracks. Steel should never be worked at a blue heat, as in this state it is very brittle. It is also mechanically tested by being heated to a cherry red, quenched in water at 82° F. then bent in a curve of small radius; if it cracks, it has become tempered, and it is therefore unsuitable for this work. If the tensile strength of the steel is under 70,000 pounds per square inch, it is sufficiently tough and ductile and can be easily worked.

In general, boiler materials are carefully tested for the following qualities:

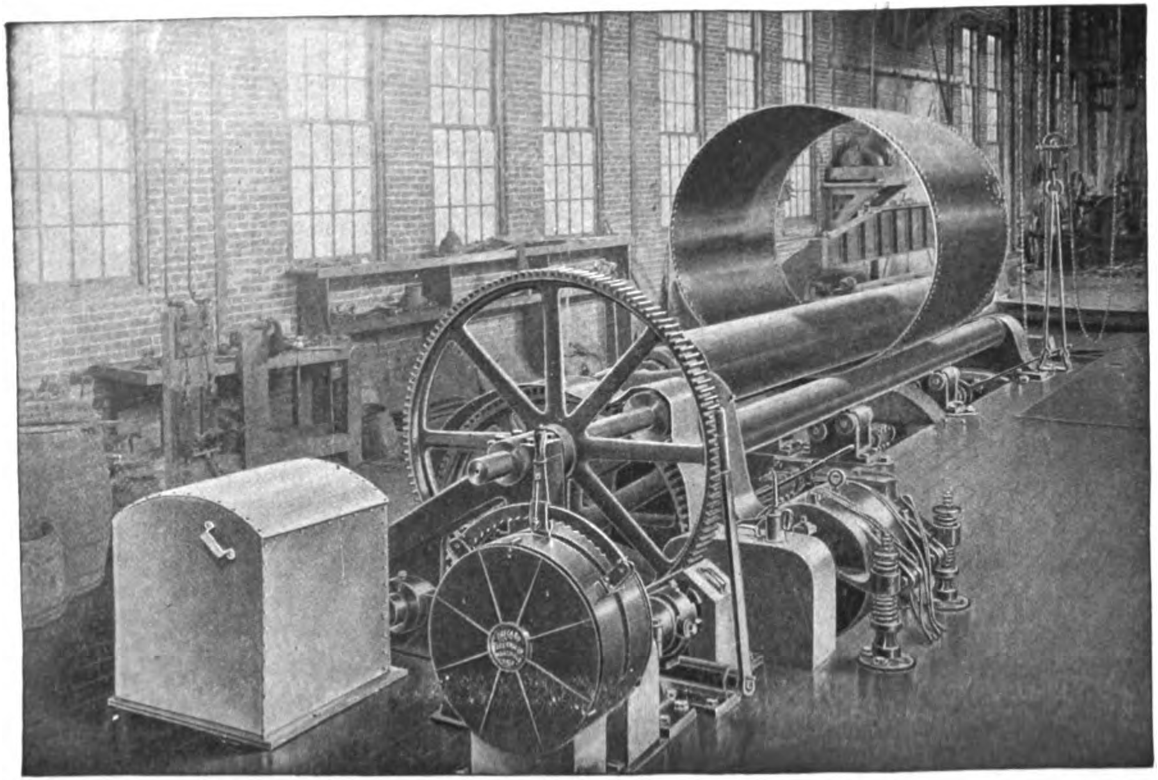
Tensile strength, to resist rupturing strains. Also in order that the plates may be thin.

Toughness and elasticity, to resist corrosion and the wear and tear of manufacture.

Ductility, so that the boiler may change its shape slightly without rupture. This is a more important quality.

BOILER CONSTRUCTION IN DETAIL.

The drawing or design of the boiler is worked out in the draughting room, as explained later under the head of Boiler Design.



TWENTY-FOOT BENDING ROLLS. CAHALL FACTORY.

The draught shows the general arrangement of the boiler, together with complete detail drawings, from which the materials are ordered. These materials are plates, rods for stays, rivets, stay bolts, tubes, steel bars, angles and channel bars for stiffening, etc.

In some boiler shops it is customary to lay the boiler out on a large blackboard full size, thereby checking the drawing. In ordering plates the blank forms are filled out in the following manner:

Messrs. John Blank & Co:

Please furnish us with the following Steel Plates, Ultimate Tensile Strength, *60,000;* Elongation, *25 per cent:*

Number wanted.	Thickness	Dimensions.	Marks.	Remarks.
6	1″	90″×70″	S 14	Shell

The dimension which runs in the direction the plate is to be bent is given first. The plates are marked as per order blank, and this serves to identify the plate when the occasion arises. When ordering any odd shape, a sketch with dimensions must be placed in the column headed "Remarks."

In ordering plates, allow for trimming, particularly in the case of irregular shapes. Rivets are sold by the pound, regardless of their shape or size. Round and flat iron may be ordered by the running foot. Manufacturers publish tables showing weight of rivets, round iron, etc., with which they furnish boiler makers.

Boiler shops are equipped with the following tools: plate rolls, plate planers, shears, drill presses, punches, countersinking machines, flanging machines, hydraulic and steam riveters, and a compressed-air system for operating pneumatic machines, such as calkers and chippers. They also have machine shops for doing

such machine work as is required for fittings, furnace fronts, etc., and a system of cranes for handling and transporting material. In connection with the above is a storeroom of sufficient size, a forge shop, and an engine and boiler for supplying the shop with the power necessary to operate it.

In boiler-shell work drilling has entirely displaced punching, and to-day all holes are drilled. Punching is cheaper than drilling, but it is more injurious to the plates and not as accurate. It is easy to see that drilling rivet holes, even if twenty are being drilled at once, is done with less strain on the plates than when done by a multiple punch forcing several holes at once. The force required to punch a plate gives the best idea of the harm done to the plate. Experiment shows that the resistance of a plate to punching is about the same as its resistance to tensile tearing. Suppose this to be 50,000 pounds per square inch; then the force required to punch the plate is the area cut out times the shearing strength, or $d \times \pi \times t \times 50{,}000$.

In which formula

d = diameter in inches and

t = thickness in inches.

For a hole $\frac{3}{4}$ inch in diameter in a $\frac{1}{2}$-inch plate, the force will be

$$\frac{3}{4} \times 3.1416 \times \frac{1}{2} \times 50{,}000 = 58{,}900 \text{ pounds.}$$

If the force required to punch one hole is 58,900 pounds, the force required in punching several holes by means of a multiple punch is enormous.

A good, ductile plate is but little injured by punching; but if of a hard, steely nature, it is likely to be seriously injured. For this reason wrought-iron plates are usually punched and steel plates are drilled. On the whole, a drilled plate is somewhat stronger than a punched plate for any kind of joint.

Some boiler makers punch the rivet holes slightly smaller than the desired size and then ream them out. By this process the injured metal around the holes is cut away. Another method to overcome the injurious effects is to anneal the plate after punching.

The ordinary process of annealing consists of heating the plate to red heat, and then allowing it to cool slowly. By this

means, hard and brittle iron or steel is made soft and tough. While the metal is hot, the surface becomes oxidized. For most purposes this scale of oxide in not harmful, but in some cases it must be removed. As this is expensive, a process of annealing in illuminating gas has been devised. The action of the gas is to reduce the oxide without altering the properties of the piece. The results obtained from annealing depend upon the kind of iron or steel, the temperature to which it is raised, and the rate of cooling. It is a great advantage to all steel of over 64,000 pounds per square inch in tensile strength, but softer steels are little better for the process.

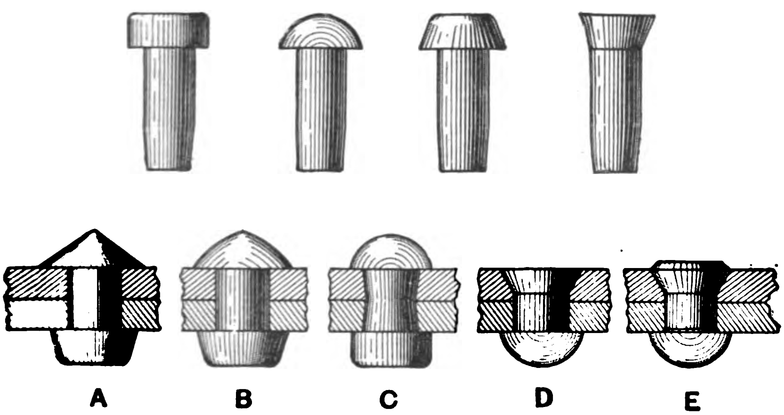


Fig. 3.

After the shell plates are planed to correct shape and the holes drilled or punched, they are put through the bending rolls and bent into a cylindrical shape, the amount of curvature being determined by a template made for the purpose. Plates are usually sheared to size, and then the edges planed with a slight bevel to facilitate calking. In the meantime the heads are being flanged by a hydraulic flanging machine; when the flange is completed, the head is put on the platen of a boring mill and turned so as to exactly fit into the shell. In some shops it is customary to punch or drill only a few holes in the shell and flange of the head, these holes serving to take bolts for holding the parts together. The back head plate is bolted into the rear course of plating, and

the parts thus assembled are hoisted up to drill if the plates, etc., have not been previously drilled or punched, otherwise to the hydraulic riveter.

RIVETS AND RIVETING.

Rivets are formed by forging, from round iron bar or mild steel, with a cup or pan shaped head. The cylindrical part, called the shank, is a little smaller than the hole and has a slight taper. Fig. 3 shows common forms of rivets. As rivets are not as reliable in tension as in shear, they are used mainly at right angles to the straining force. If the stress is parallel to the axis, bolts are used, since they are strong in tension. The shearing strength of steel rivets is about 45,000 pounds per square inch, and of iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel plates, but many boiler makers prefer to use iron rivets in all cases.

Three types of rivets in use are shown in Fig. 4, the following table giving the dimensions:

Diameter of Rivet.	Cone Head. A			Countersunk. B		Button Head. C	
D	E	F	G	E	G	E	G
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{19}{32}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$
$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{21}{32}$	$\frac{39}{64}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
1	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{27}{32}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{3}{4}$

Formerly all joints of boilers were riveted by hand, but now all riveting is done by machines, except those joints to which a machine cannot be applied. If done by hand, the red-hot rivet is inserted in the hole, and the second head formed by two riveters working with hammers. This head is either made conical by the hammers alone or finished with a cup-shaped die called a "snap." This latter is the more usual method. The disadvantages of hand riveting are slowness and a tendency to form a shoulder before the rivet fills the hole.

Machine riveting is preferable, as the work is done better, faster and more accurately; the pressure coming gradually on the entire rivet, compresses it completely into the hole before the head is formed. Before riveting, care should be taken that the plates are close together, so that a shoulder will not be formed between the plates and prevent a good joint. Rivets should always be put in while red hot, for in this condition they are more easily worked, and when they cool they contract, nipping the plates together in a tight joint.

Hydraulic riveting is more gradual and is generally preferred to steam riveting. The pressure from the steam riveter often comes as a sudden blow and does not allow time for the rivet to completely fill the hole.

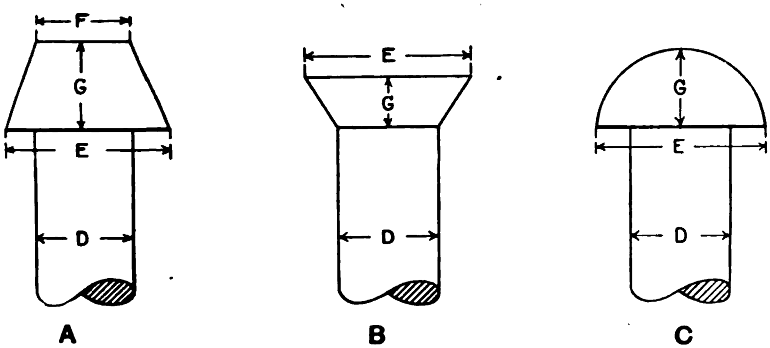


Fig. 4.

It is sometimes desirable to rivet with a countersunk head; that is, the rivet does not project above the plate. The countersunk head is formed by hammering down the end of the rivet into the countersink in the plate. This form is shown at D, Fig. 3. This joint is often used in shipbuilding and in boiler making when it is necessary to attach mountings. It should always be avoided, if possible, on account of its weakness, and especially when the straining force acts in the direction of the length of the rivet, as the head has a very insecure hold and is likely to be pulled through the hole.

Rivets may be tested in a boiler shop as follows: the rivet to be bent cold in the form of a hook around another rivet of the

same diameter, and show no flaws or cracks; to be bent hot down upon itself and show no cracks, head to be flattened while hot until its diameter is $2\frac{1}{2}$ times the diameter of the shank, and show no flaws.

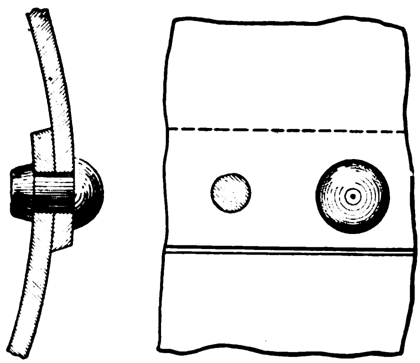


Fig. 5.

The uniform heating of steel rivets is of more importance than in the case of iron rivets, where it is sufficient to heat the points only. Steel rivets also should not be heated to a white heat, as iron rivets are, but to a bright cherry red, for if heated beyond this point they will burn. The fire in which steel rivets are heated should be kept thick, and the draught moderate. This should also be observed in heating steel plates for flanging.

There are various forms and strengths of riveted joints. It

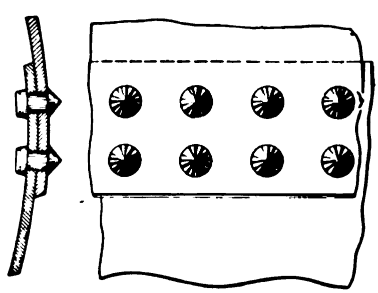


Fig. 6.

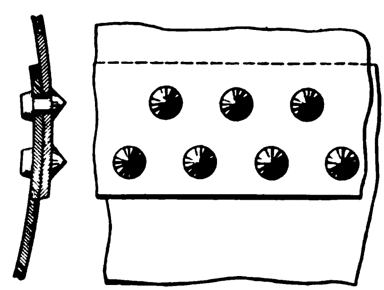


Fig. 7.

is obvious that in punching or drilling, a plate is weakened to the extent of the sectional area cut out, and that if the holes are punched, the metal between the holes is weakened. In treating the strength of a joint it is customary to speak of it as a percentage of the strength of an unpunched plate.

If one plate overlaps another and is riveted to it by a single

row of rivets, as shown in Fig. 5, it is called a single-riveted lap joint. This joint has about 56 per cent of the strength of a solid plate. If another row of rivets is added, it is called a double-riveted lap joint; Fig. 6 shows the double-riveted lap joint chain riveted, and Fig. 7 the double-riveted lap joint zigzag riveted.

Double riveting is done in two ways: zigzag, or staggered, and chain. When rivets are put in so that the rivets of one row are opposite the spaces of another row, it is called zigzag riveting or staggered riveting. If the rivets are placed immediately opposite each other, it is called chain riveting.

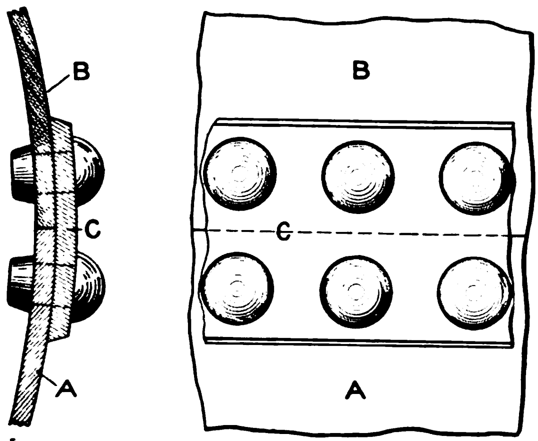


Fig. 8.

If the two plates are kept in the same plane and a cover or butt strap riveted on, it is called butt riveting (Fig. 8, in which A and B are the boiler plates, and C is the butt strap). If an inside butt strap is added, it is called a double butt joint (Fig. 9). Fig. 10 shows a treble-riveted butt joint. A single butt joint is about equal in strength to a lap joint having but one row of rivets, but a double butt joint is considerably stronger.

In this latter form of joint the rivets have double shearing surfaces, since they tend to shear off in two planes. This either makes a stronger joint or allows the use of smaller rivets. In the single butt joint the butt strap is usually about $1\frac{1}{8}$ the thickness of the plate, and if the inside butt strap is added, each butt strap

is made about $\frac{5}{8}$ the plate thickness. Butt joints are now being used in the best class of boilers, and are used almost entirely for plates less than $\frac{1}{2}$ inch in thickness.

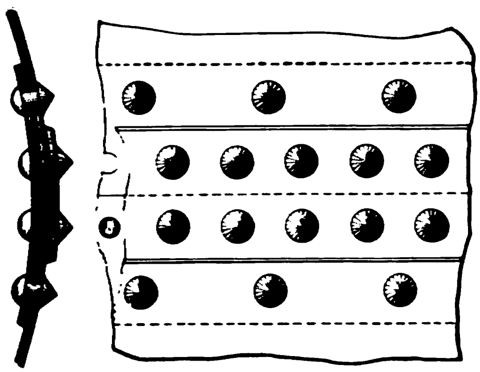


Fig. 9.

Lap joints are used for circumferential seams, and the stronger joint, the butt, for longitudinal joints. For high pressures in marine boilers, triple riveting is frequently used.

If a cover plate is riveted on the outside of a lap joint, it is called combined lap and butt joint. In this case there are three rows of rivets, the middle row having twice as many rivets as the outer rows. Fig. 11 shows the combined joint.

The distance between the centers of rivets is called the "pitch." The mathematical calculation of pitch and the distance between the rivets and the edge of the plate will be taken up later.

The following table gives an idea of the relative strengths of riveted joints:

Kind of Joint.	Riveting.	Percentage of Strength.	
		Punch.	Drilled.
Lap	Single Double	55 69	62 75
Single Butt	Single Double	55 69	62 75
Double Butt	Single Double	57 72	67 79

FLANGING IRON AND STEEL PLATES.

Iron plates are more severely tested by flanging than by any other work done upon them. This is due to their fibrous nature, and great care is necessary to prevent breaking in the bend, if the corner is sharp.

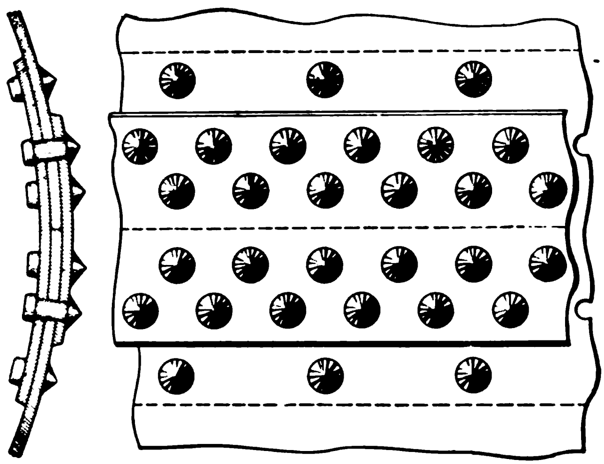


Fig. 10.

As has been stated, steel requires uniform heating and moderate curves. Flanging is almost entirely done to-day by machines. After flanging, the steel should be annealed by heating the whole plate uniformly to a dull red heat, and allowing it to cool slowly.

WELDED JOINTS.

Welded joints for boiler shells are desirable. By their use deposits which accumulate on and around rivet heads and joints, corrosion caused by leakage, and loose rivets, are done away with, and calking also. Moreover, a perfectly welded joint is stronger than the best riveted joint, and approximates nearly to the original strength of the plate. Welded steam drums are used now quite extensively for water-tube boilers of the marine type.

The soundness of such a joint is a matter of uncertainty, and

depends upon the skill and care of the workmen. It is impossible, from external appearances, to judge the soundness of a welded joint. The principal use of welded joints is for furnace tubes and steam domes, but they have not been used much for boiler shells. The lack of tests on welded joints and the small amount of information on the subject, render the results of experiments of little value. The weld is best made when the edges of the plates are upset, at red heat, to nearly double the plate thickness, and beveled to an angle of about 45 degrees. The edges are then heated together, and the weld made by hammering down the joint to the original thickness of the plate.

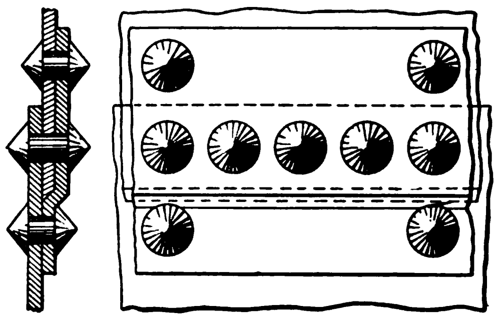


Fig. 11.

ARRANGEMENTS OF PLATES AND JOINTS.

When we take up the design of boilers we shall see that a boiler tends to rupture longitudinally. The reason for this is that the resistance of a thin cylinder to circumferential rupture is double the resistance to longitudinal. Since this is the case, lap joints are used for transverse seams, and a stronger form (the double butt joint) is used for the longitudinal.

At the junction of three or more plates, where the circumferential and longitudinal joints meet, ordinary riveted joints would be too thick. To overcome this difficulty, two or more plates are forged thin at the joint, as shown in Fig. 12.

Whenever longitudinal and girth seams meet, the plates should be arranged to "break joints"; that is, one longitudinal seam should not be a continuation of another. The proper arrangement is shown in Fig. 13.

In both vertical and horizontal boilers the inside lap is made to face downward, so that it will not form a ledge for the collection of sediment

The belts of plates that make up the length are sometimes arranged conically, with the outside lap facing backward. When the boiler is slightly inclined toward the front end, this conical arrangement facilitates draining and cleaning, as the dirt is removed at the front end. This is a great advantage to internally fired boilers, as they are difficult to clean.

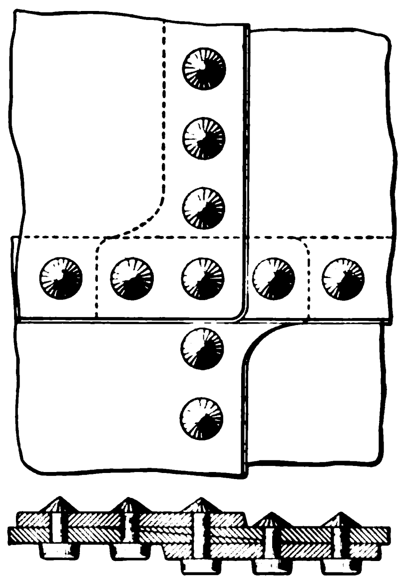


Fig. 12.

In long vertical boilers the ring seams are arranged with the inside lap facing downward, so as not to have a ledge for sediment. Sometimes the belts of locomotive boilers are arranged telescopically, with the largest diameter at the fire-box end. Of late years the best makers use larger plates than formerly. This is advantageous, espe-

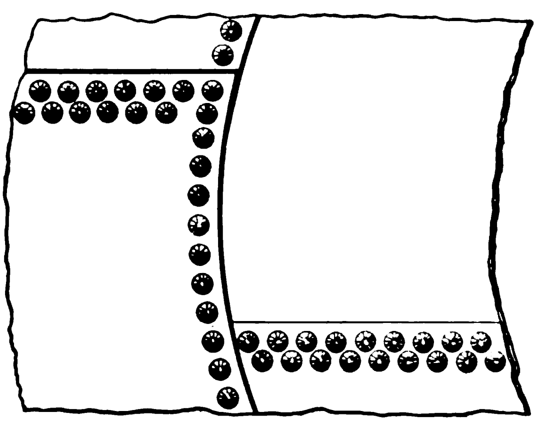


Fig. 13.

cially in externally fired multitubular boilers, as the single seam is placed above the water-level, and therefore is away from the fire.

The portion of a boiler between the shell and the furnace is called the water leg. Figs. 14 to 20 inclusive illustrate the method of construction of the water leg and the joints around the furnace door. Figs. 14 and 15 show two methods of constructing

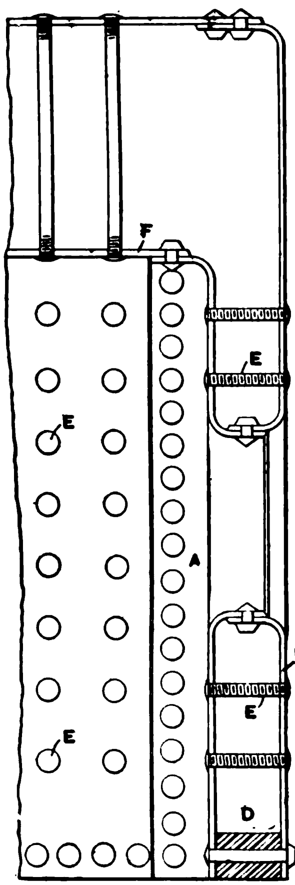


Fig. 14.

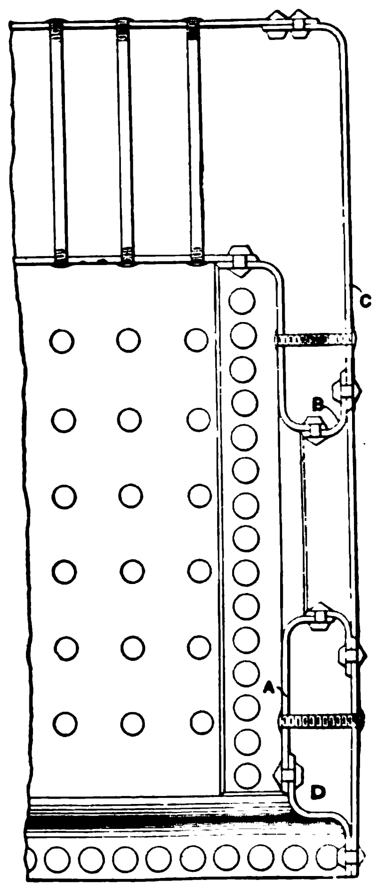


Fig. 15.

the water leg. In Fig. 14 the exterior plate and the furnace plate are riveted to the ring D by means of long rivets. This ring is usually made of wrought iron, but in many cheap boilers it is of cast iron. In Fig. 15 the two plates are riveted to the flanged ring D. This construction is better than the solid cast-iron ring, on account of flexibility, but the junction of the plates D and C

forms a corner in which sediment is deposited. In Fig. 17 the plate B is flanged and riveted to C. This arrangement requires less riveting than the one shown in Fig. 15. Figs. 14, 15 and 17 also show three forms of construction of the joints around the

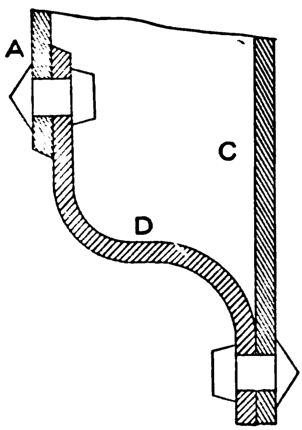


Fig. 16.

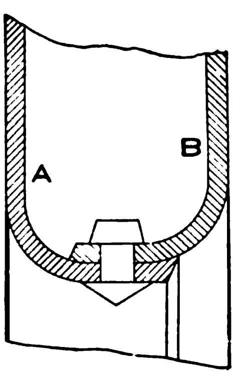


Fig. 18.

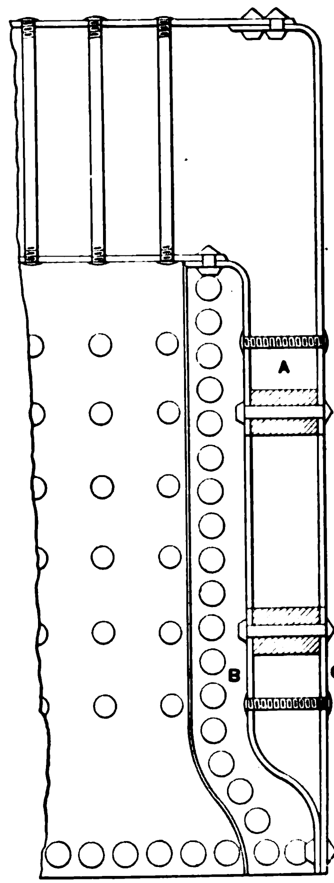


Fig. 17.

furnace door. In Fig. 14 both the exterior plate and the furnace sheet are flanged and riveted together. This is shown in an enlarged view in Fig. 18. The construction shown in Figs. 15 and 19 is not as good as that in Fig. 14, because of the extra riveting; also, it has two corners, B and C, for the deposit of sediment. Fig. 17 shows a somewhat different form of furnace construction,

the two plates being riveted to the cast-iron ring. This form is better shown in Fig. 20. It makes this part of the boiler too rigid, but it has the advantage of not having rivet heads to wear off. In these methods of riveting, those which have the flanged ring are preferable to those using the cast-iron ring, because of more freedom for expansion; but the flanged ring forms an undesirable corner.

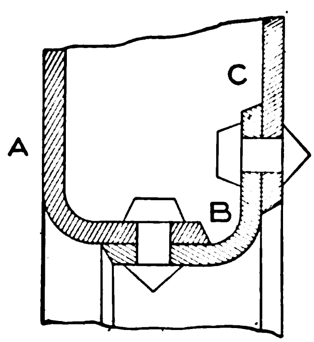


Fig. 19.

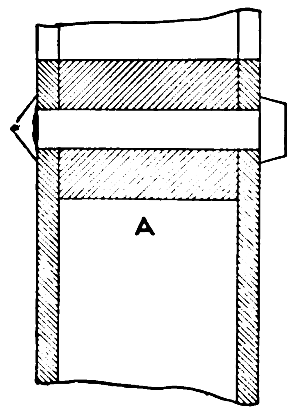


Fig. 20.

In almost every boiler, plates must be connected at right angles. An example of this is seen where the end plates are jointed to the shell plates of cylindrical boilers. There are three principal methods: riveting both plates to an angle iron, riveting to a flanged ring and flanging the end plate. In Fig. 21 the two plates are riveted to an angle iron, which is made of wrought or cast iron. This construction is too rigid; the constant variations of temperature cause repeated changes of form, which tend to crack the angle iron on the inside of the plate at the joint. Corrosion increases the evil, as it rapidly attacks iron which has once been cracked or broken. There is no definite rule for the dimensions of these angle irons, but it is safe to make the mean thickness a little greater than that of the plates.

The forms shown in Figs. 22 and 23 are better. The head is flanged and riveted to the shell plates. The flanging makes a more flexible joint. The radius of the curve of the flange should be about four times the thickness of the plate. The head and

shell are sometimes connected to a flanged ring, as shown in Fig. 24. The extra row of rivets makes a complex joint.

In vertical boilers the external fire-box is joined to the cylindrical shell by riveted joints. Figs. 25 and 26 show two forms; that in Fig. 25 being the better on account of the flanged ring,

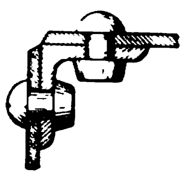


Fig. 21.

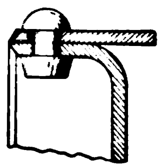


Fig. 22.

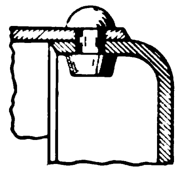


Fig. 23.

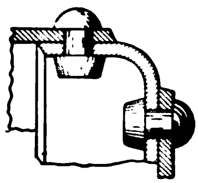


Fig. 24.

which allows expansion and contraction of the shell and furnace plates.

Sometimes the case occurs of connecting two plates which are parallel and near together. For instance, at the bottom of the

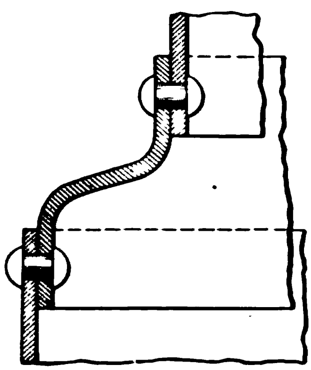


Fig. 25.

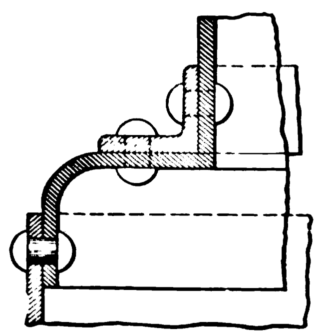


Fig. 26.

locomotive fire-box a connection must be made between the inner and outer fire-box. The water-leg construction is a similar case. Several methods for this construction are shown in Fig. 27. Fig. 27A is too complicated and is undesirable, both on account of the numerous rivets and angle irons, and on account of the inside joints, which cannot be calked. Fig. 27B is better, since it has but one angle iron; it has, however, the undesirable inside joint.

Fig. 27D is a good joint, the form of connection being called a channel iron. Fig. 27E, as we have seen, is a good flexible joint, but it has the undesirable corner where sediment lodges.

We have thus briefly discussed the various methods and arrangements for putting shells together, and now let us return to our boiler, which is ready for riveting at the hydraulic riveter. A few rivets are first driven at equal intervals around the ring seam

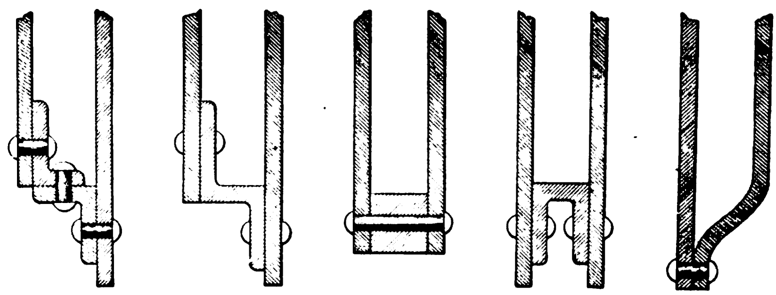


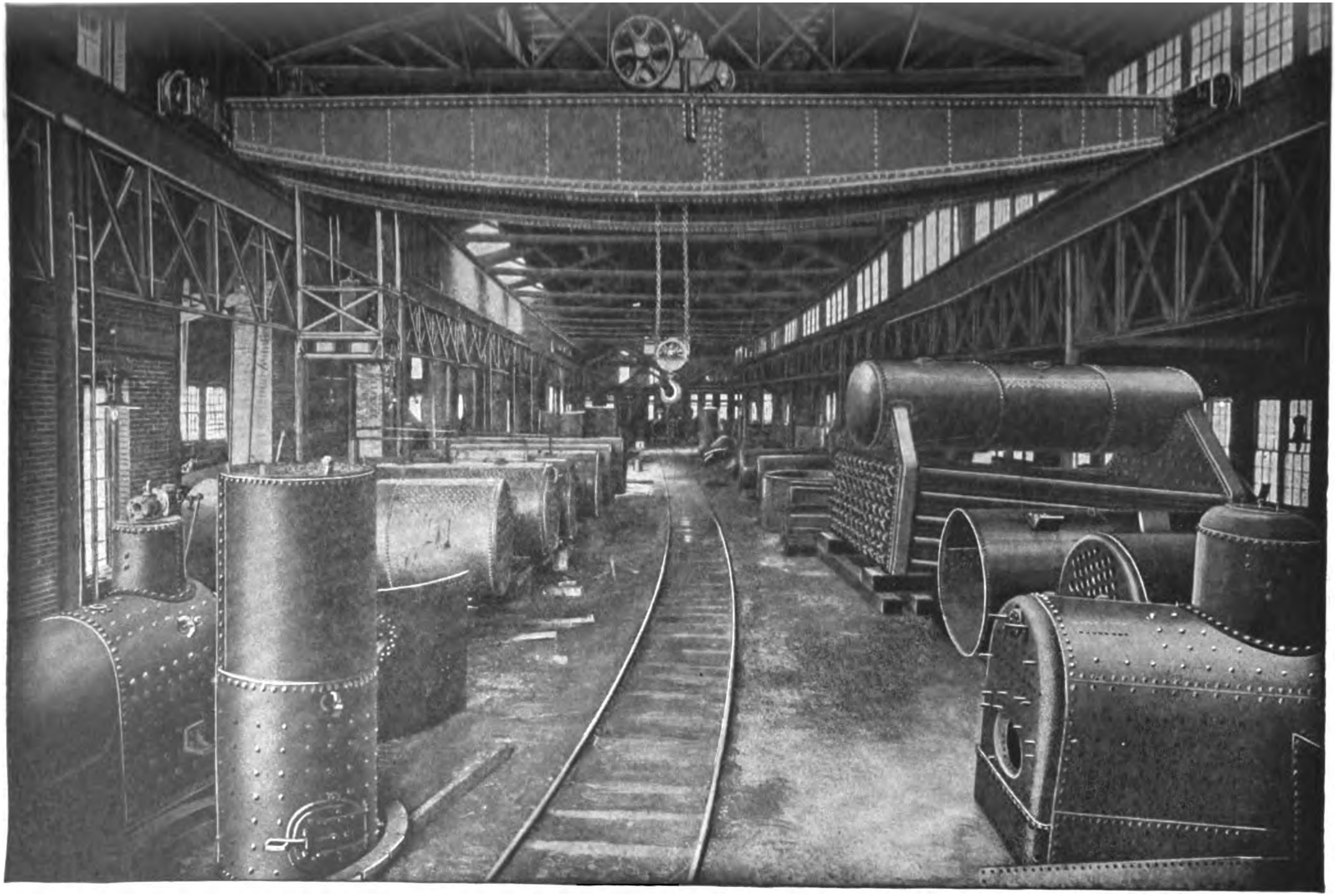
Fig. 27.

at the back head. The reason for driving only a few rivets is that any errors in the spacing of the holes are distributed and not accumulated, as would be the case if they were driven in succession. From this point on, the riveting is continued until the shell is completely riveted up.

STAYING.

The shell is now ready to receive the stays. When under steam, a cylindrical shell is strained by internal pressure in two directions, namely: transversely, by a circumferential strain due to the pressure tending to burst the shell by enlarging its circumference, and longitudinally, by the pressure on the ends. If a boiler were spherical it would require no stays, because a sphere subjected to internal pressure tends to enlarge but not to change its shape. All flat surfaces in boilers must be stayed, otherwise the internal pressure would bulge them out and tend to make them spherical in shape. The ends of steam drums on high-pressure water-tube boilers are often made hemispherical.

The first and most important point in staying is to have a



ERECTING SHOP.
E. Keeler Company.

sufficient number of stays so that they will entirely support the plate without regard to its own stiffness. The second is to have them so placed as to present the least obstruction to a free inspection, and third, to have them so arranged as to allow a free circulation of water. Too much care cannot be taken in fitting stays and braces, as they are out of sight for long periods, and a knowledge of their exact condition is not always easily obtained. In the ordinary fire-tube boiler the principal surfaces stayed are: the flat ends, crown sheets, flat sides of locomotive boilers and combustion chambers of cylindrical marine boilers. In the case of most marine or Scotch boilers, the diameter is large compared to the length; hence the flat surface is considerable, and needs careful staying. All the plates that are not cylindrical or hemispherical must be stayed. The details should be arranged for each boiler; a few general methods and cautions can, however, be given.

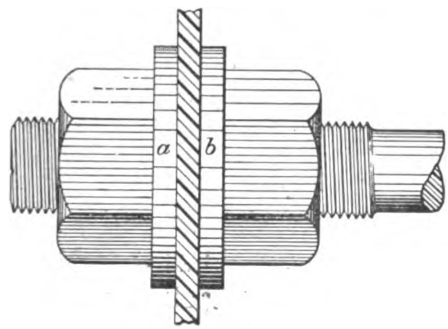


Fig. 28.

The most common and simple form of stay is a plain rod. It is used to stay the flat ends of short boilers. This stay is a plain

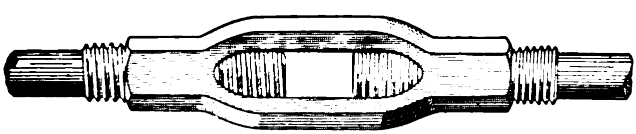


Fig. 29.

rod passing through the steam space and having the ends fastened to the heads. The ends are fastened and the length adjusted in a variety of methods; the simplest being nuts on both sides of the plate, as shown in Fig. 28. The copper washers *a* and *b* strengthen the plate and prevent abrasion by the nuts. In place of the nuts the rod is often bolted to angle irons, which are riveted to the plates. In this case, turn buckles similar to the one shown in Fig. 29 are used for adjusting the length.

The stays are usually from $\frac{3}{4}$ inch to an inch in diameter, and are made of wrought iron or steel, with an allowable stress of 5,000 to 7,000 pounds per square inch. If the ends are fastened to riveted angle irons, the combined area of the rivets is made a little greater than that of the rod.

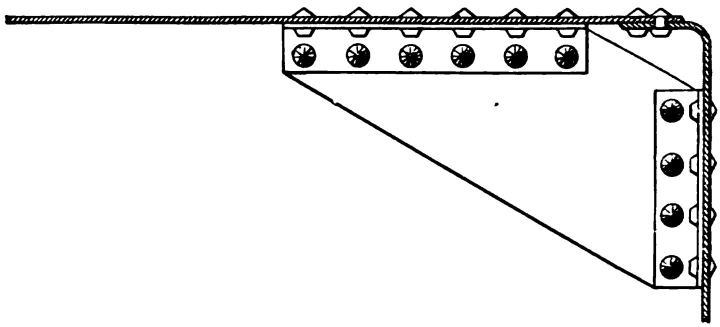


Fig. 30.

If a boiler is long, that is, more than 20 feet, long stays would sag in the middle and not take up the full stress on the end plates. For long boilers, gusset and diagonal stays are used. This form of boiler stay, shown in Fig. 30, is made of wrought-

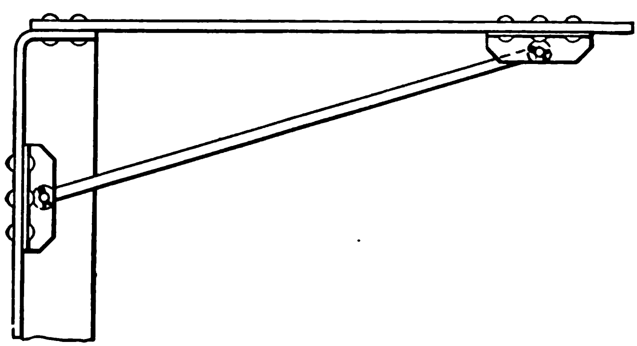


Fig. 31.

iron plate riveted to angle irons; the angle irons being riveted to the end and shell. Boilers of the Cornish, Lancashire and Galloway types often have this kind of stay. These boilers are internally fired, and as the variation of temperature causes expansion and contraction, great care should be used in placing the gusset

stay. If the stay is too near the flange or too many stays are used, the head will be too rigid and have a tendency to crack.

A form of diagonal stay is shown in Fig. 31. The plain rod is connected to angle irons by means of split pins. The angle irons are fastened to the shell and end by rivets or bolts. Another form of diagonal stay, called the crowfoot, is shown in Fig. 32. The two ends are bolted or riveted to the end and shell.

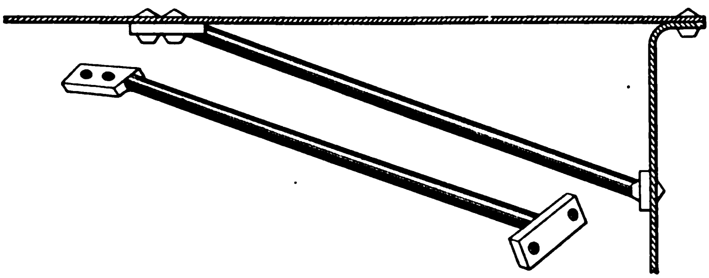


Fig. 32.

The angle between the shell plate and stay rod should be small,— not more than 30 degrees. The rod itself is designed for tensile strength, since the diagonal pull may be easily reduced to an equivalent direct pull. A large factor of safety is used to provide for future corrosion.

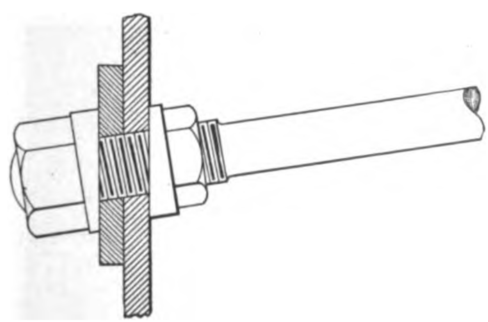


Fig. 33.

For marine boilers, a modified crowfoot stay (Fig. 33) is often used. The end passing through the head is supplied with nuts and taper washers, the washers having the proper taper to allow the nuts to be set up tightly against them.

In locomotive fire-boxes and in the combustion chamber of marine boilers, there are two flat or slightly curved surfaces that must be stayed together. These are riveted by short screw stay bolts. The bolts shown in Figs. 34 and 35 are screwed in place, and the ends riveted over. In marine boilers these stays are fastened with nuts, as shown in Fig. 36, instead of being riveted.

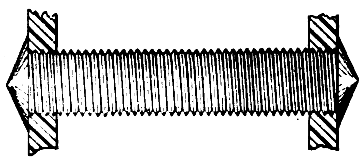


Fig. 34.

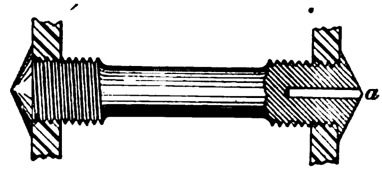


Fig. 35.

Sometimes the bolt is threaded the entire length, as in Fig. 34, or is turned off smooth in the center, as in Fig. 35. The smooth surface resists corrosion, and is less likely to fracture than the threaded bolt. Sometimes a small hole is drilled in the end, so that if the bolt breaks, the escaping steam will give warning. This is shown at *a*, Fig. 34. These bolts are $\frac{7}{8}$ inch or 1 inch in diameter.

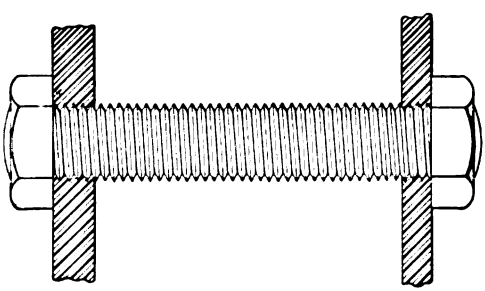


Fig. 36.

The strains which come on a stay bolt are not the same as those on rivets or on ordinary stay rods; as a matter of fact, stay bolts fail by a bending stress, and generally fracture just inside the outside sheet, due to the unequal expansion between combustion chamber or furnace and the outside boiler shell. Owing to this difference of expansion, flexible stay bolts have been designed, but have not come into general use, nor are they likely to, as they occupy considerable space and are much more complicated than the simple stay bolt. Stay bolts are made from the best quality of refined iron, which has been found to stand the strains of alternate heating and cooling better than mild steel. Iron stay bolts are more durable, because of the fibrous nature.

It should be added that boiler heads are further stiffened by channel bars or angles placed along the line of holes for the through stay rods.

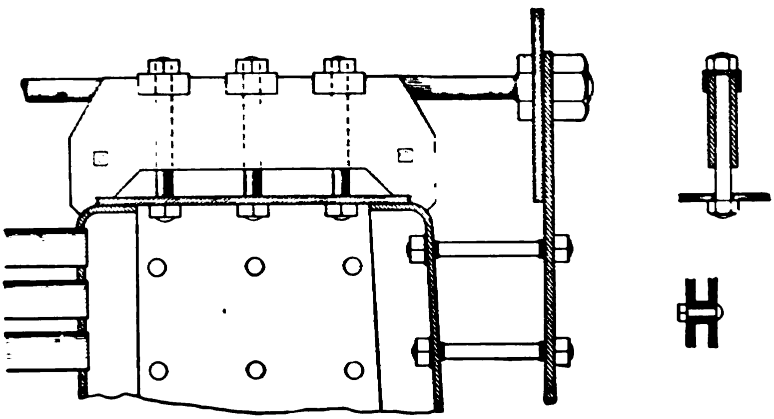


Fig. 37.

The crown sheets of fire-boxes and tops of combustion chambers are usually stayed by crown bars, which extend across the flat surfaces, as shown in Fig. 37, the ends resting on the

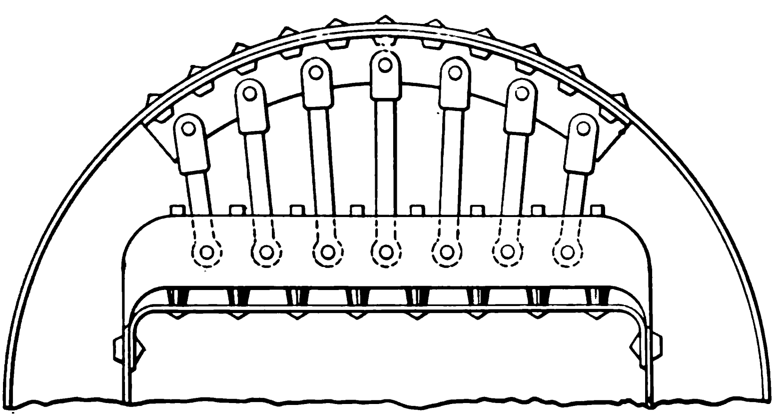


Fig. 38.

side plates. Bolts about 4 inches apart connect the crown sheet to this girder. The girder may be a solid bar, or it may be made up of two flat plates bolted or riveted together, as shown in the figure, the stay bolts being placed between the plates at intervals

of about 4 inches. Either bolts or rivets may be used to keep the plates which form the girder from spreading. Projections are sometimes forged on the bottom of the girder, so that the stay bolts may be screwed up tightly without bending the plate.

The depth of the plates which make up the girder vary from

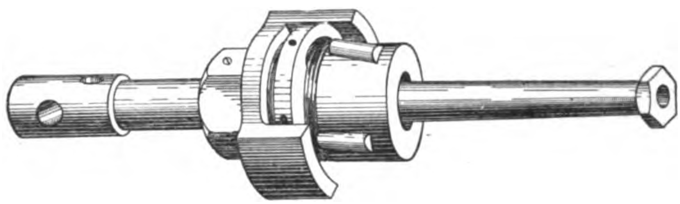


Fig. 39.

4 to 6 inches. They are from $\frac{5}{8}$ to $\frac{3}{4}$ inch in thickness. If bolts $\frac{7}{8}$ inch in diameter are used, the distance between the plates is usually 1 inch, but if larger bolts 1 inch in diameter are used, the distance should be $1\frac{1}{8}$ inches. The ends of the bars which rest upon the side plates should be carefully fitted to make a good bearing, and the area should be sufficient to prevent crushing of

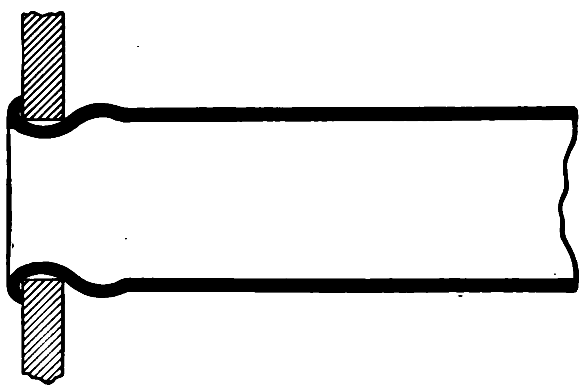


Fig. 40.

the end plates. The distance between the crown sheet and the girder should be at least $1\frac{1}{2}$ inches, so that there will be good circulation and the plates may be readily cleaned.

In some cases the girder is supported from the shell by sling stays, as shown in Fig. 38. The sling stays are connected to the

girder and to an angle iron, or T-iron, which is riveted to the shell. The angle iron stiffens the shell. In designing this form of stay it is usual to make the girder strong enough to support the crown sheet without any sling stays, and these stays are used for additional support.

TUBES.

Boiler tubes are made of steel or wrought iron, but most commonly of charcoal iron and lap welded. In the formation of the lap the plate is upset, then bent around until the thickened edges lap sufficiently. It is then heated successively about 8 inches at a time, and welded over a mandrel, which is a cast-iron

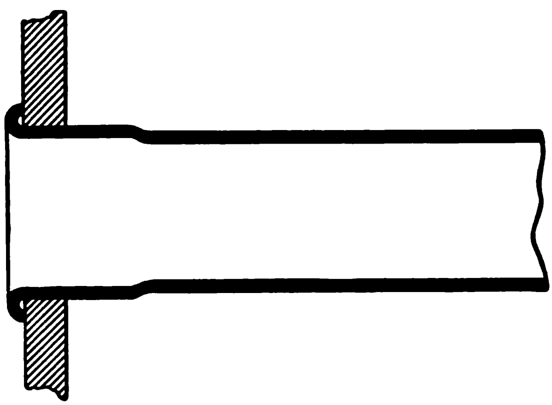


Fig. 41.

arm with a slightly convex top, over which the tube is placed. Tubes are measured by their outside diameters, and are usually true to gauge, so that holes for them may be bored without taking measurements from the tubes themselves.

The holes for the tubes in the tube sheet are usually made in one of two ways. One method is to punch the tube holes the proper size by means of a helical punch. With this punch the metal is cut away by a shearing cut. The holes ought to be punched a little under size, and then reamed out, so that the surface against which the tubes are expanded may be good. The other method is to punch or drill a small hole at the point marking the center of the tube hole. A drill with a post in the center, which fits the small hole, then drills the desired size of hole.

Ordinary tubes are fastened to the end plates by expanding the metal of the tube against the tube plate. This is done by a tool called an expander, of which there are two common forms. One form consists of a steel taper pin and a number of steel segments, held in place by a spring. The outside of the segments

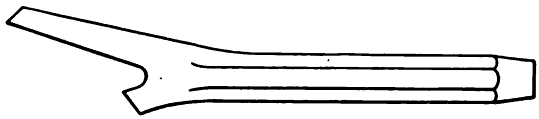


Fig. 42.

have the form to be given to the expanded tube, and the inside is a straight hollow cone, into which the steel taper pin fits. The segments are forced apart by hammering on the steel pin. In order that the metal of the tube may not be injured, the hammering should be done gradually and carefully, and the expander turned frequently. Another form, shown in Fig. 39, has a set of rolls that are forced against the inside of the tube by driving in the taper pin. The pin and rolls rotate as the pin is driven, and the rolls gradually expand the tube against the tube plate.

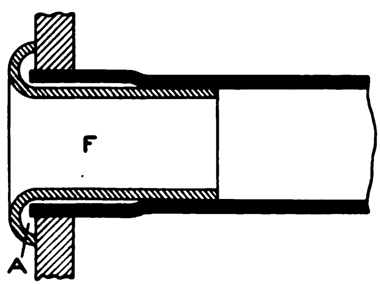


Fig. 43.

Two forms of tube expansion are shown in Figs. 40 and 41. That shown in Fig. 41 is preferable to that in Fig. 40, as the latter bears at the corners only, while the former bears against the entire thickness of the tube sheet.

After the tubes are expanded, the ends are beaded over, as shown in Figs. 40 and 41. This adds to the strength of the connection between the tube and tube sheet. The tool commonly used for this beading is shown in Fig. 42.

Ferrules are often placed in the ends of fire tubes, and serve to protect the ends from the intense heat of the fire. The arrangement is shown in Fig. 43, the ferrule F being placed within the tube for a short distance. The space A is merely an air space.

Stay tubes are not used as extensively at the present time as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from such tests that the holding power of tubes expanded, as shown in Fig. 40, is more than equal to the pressure on the spaces between the tubes of an ordinary tube plate. Stay tubes are simply heavier tubes, with the ends pro-

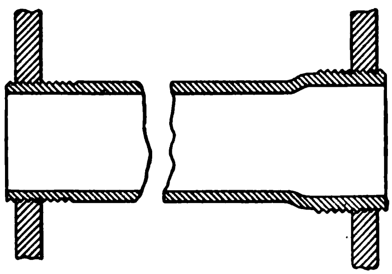


Fig. 44.

jecting beyond the tube sheet and threaded for shallow nuts. The ends of the tubes are frequently upset or thickened, and screwed into the tube sheet as well. This form is shown in Fig. 44.

FURNACE FLUES.

Flues which are subjected to external pressure should always be cylindrical. Fig. 45 shows the section of the Adamson

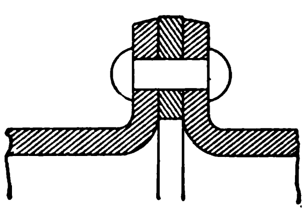


Fig. 45.

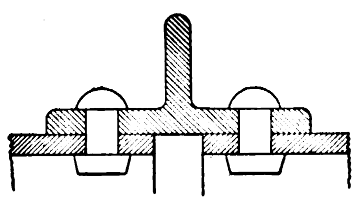


Fig. 46.

flue. This was an improvement over the plain furnace, as it is more elastic and allows expansion; the flanged rings also strengthen and stiffen it against collapse. The methods of building furnaces shown in Figs. 46 and 47 are not considered as good as the Adamson arrangement. Fig. 46 is too rigid, and does not

allow a free expansion and contraction. Fig. 47, on the other hand, permits of such extremely well, but both have the fault of exposing a double thickness of plates and two rows of rivets to the fire.

The corrugated flue shown in Fig. 48 is popular and, furthermore, is excellent. There is freedom for expansion throughout its whole length, thereby reducing the strains on the boiler.

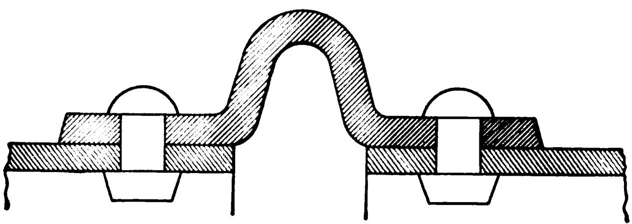


Fig. 47.

The plates should be thick enough to prevent sagging in the middle, the thickness usually varying from $\frac{5}{16}$ inch to $\frac{5}{8}$ inch. Corrugated furnaces are riveted to the rear tube sheet in the return tube boiler of the marine type, the end of the furnace being

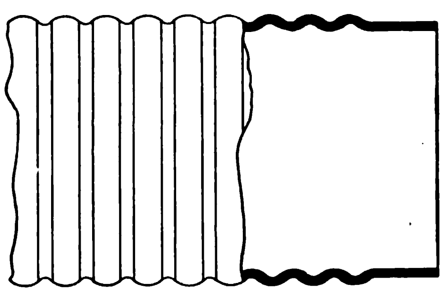


Fig. 48.

flanged at the front; and the head of the boiler is flanged around the opening cut for the furnace, which fits well into the flange.

CALKING.

In order that riveted joints of boilers may be steam and water tight, they generally require calking. This process upsets the metal of the overlapping plate, or burrs down the edge,

forcing it into close contact with the lower plate, and rendering the joint steam tight.

The calking tool is similar to a chisel, the end having a variety of shapes. Fig. 49 shows a round-nosed tool which burrs down the upper plate without cutting the under plate; but it is hard to start, and in calking with such a tool the edge is first started with a sharper round-nosed tool, and then finished with one as indicated in the figure. If a square-end tool is used, as shown in Fig. 50, the under plate is likely to be cut, and the plates between the edge and the rivet be separated. The most common form of calking tool is one similar to the one shown in

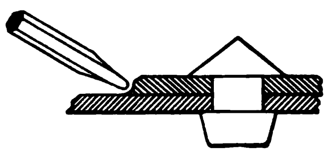


Fig. 49.

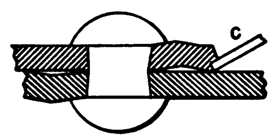
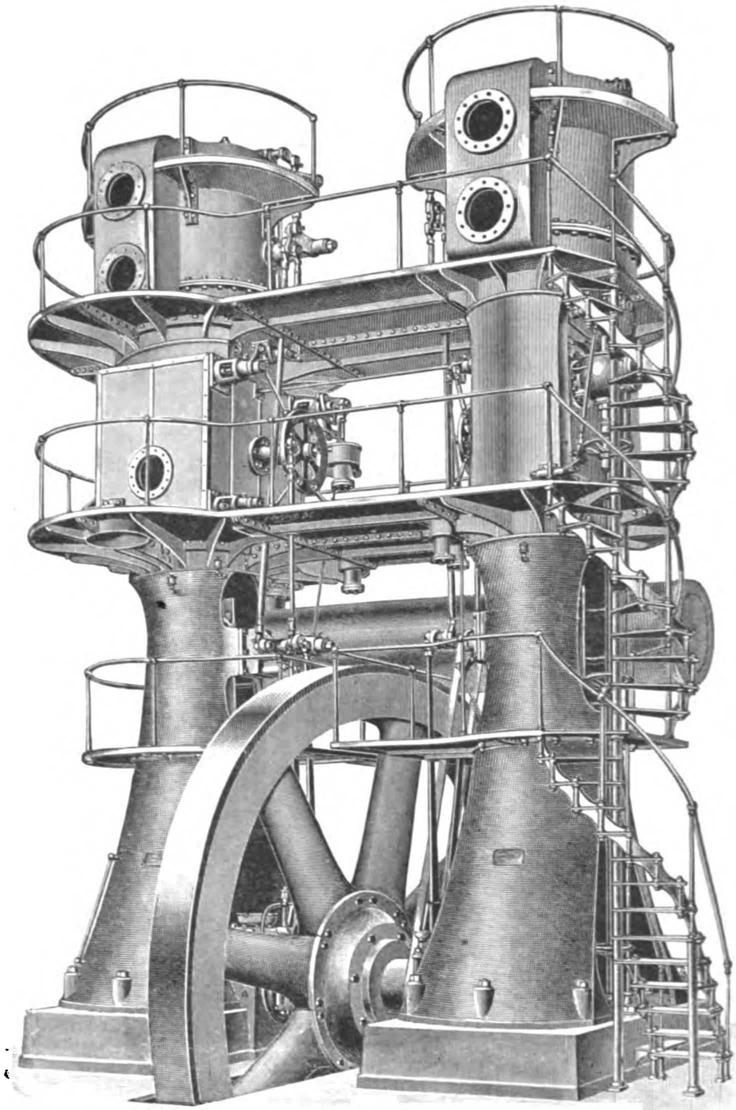


Fig. 50.

Fig. 49, except that the end is flat, with a slight bevel, and not round.

A slight bevel given the plates makes both calking and fullering more easily done. When the calking tool is thin it is sometimes driven by careless workmen into the joint, wedging the plates open. Severe and careless calking is very injurious to boilers. On the inside it often causes grooving and fracture, and the fracture of plates then follows the line of calking rather than the line of rivet holes. A pneumatic calking machine is often used in boiler shops, as it does this work about four times as rapidly as it can be done by hand. It resembles a rock drill in general principles. Air is supplied through a flexible tube, at a pressure of about 70 pounds per square inch. It makes about 1,500 strokes a minute.



VERTICAL COMPOUND BLOWING ENGINE
ALLIS-CHALMERS COMPANY

THE STEAM ENGINE.

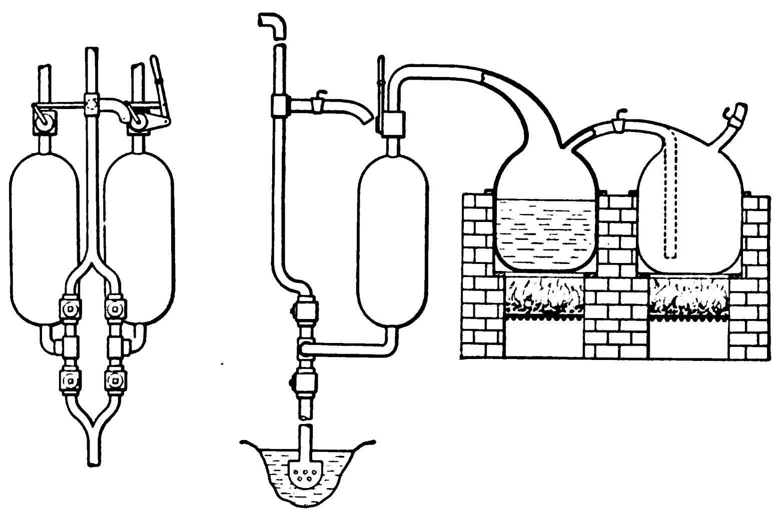
There are various kinds of engines from which mechanical work is obtained by the expenditure of heat. In the gas engine a mixture of gas and air is burned in the cylinder, the heat thus generated being converted into work by the expansion of the products of combustion. The action in oil and hot-air engines is very similar. The most important of all heat engines, however, is the steam engine, in which the heat in steam is transformed into work. It will be useful to review briefly some of the stages through which it has passed in its development.

The first steam engines of which we have any knowledge were described by Hero of Alexandria, in a book written two centuries before Christ. Some of them were very ingenious, but the best were little more than toys. From the time of Hero until the seventeenth century there was very little progress. At this time there began to be great need of steam pumps to remove water from the coal mines. In 1615, Salomon de Caus devised the following arrangement. A vessel, having a pipe leading from the bottom, was filled with water and then closed. Heat applied to the vessel caused steam to be formed, which forced the water through the pipe.

A little later an engine was constructed in the form of a steam turbine; but it was unsuccessful, and the attention of inventors was again turned to pumps.

Finally Thomas Savery completed, in 1693, the first *commercially successful* steam engine. It was very wasteful of steam as compared with our engines of today, but as being the first engine to accomplish its task it was a grand success. Savery's engine (Fig. 1) consisted of two oval vessels placed side by side and in communication with a boiler. The lower parts were connected by tubes fitted with suitable valves. Steam from the boiler was admitted to one of the vessels and the air driven out. The steam was then condensed and a vacuum formed by letting

water play over the surface of the vessel. When the valve opened, this vacuum drew water from below until the vessel was full. The valve was then closed and steam again admitted, so that on opening the second valve the water was forced out through the delivery pipe. The two vessels worked alternately. When one was filling with water, the other was open to the boiler and was being emptied. Of the two boilers, one supplied steam to the oval vessels and the other was used for feeding water to the first boiler. The second boiler was filled while cold and a fire lighted under it. It then acted like the vessel used by Salomon de Caus and forced a supply of feed water into the main boiler.



END VIEW. Fig. 1. SIDE VIEW.

A modification of Savery's engine, the pulsometer (Fig. 2), is still quite common. It is used in places where an ordinary pump could not be used and where extreme simplicity is of especial advantage. Its valves work automatically and it requires very little attention.

A serious difficulty with Savery's engine resulted from the fact that the height to which water could be raised was limited by the pressure which the vessels could bear. Where the mine was very deep it was necessary to use several engines, each one raising the water a part of the whole distance. The consumption of coal

in proportion to the work done was about twenty times as great as that of a good modern steam engine. This was largely, though not entirely, due to the immense amount of steam which was wasted by condensation when it came in contact with the water in the oval vessels.

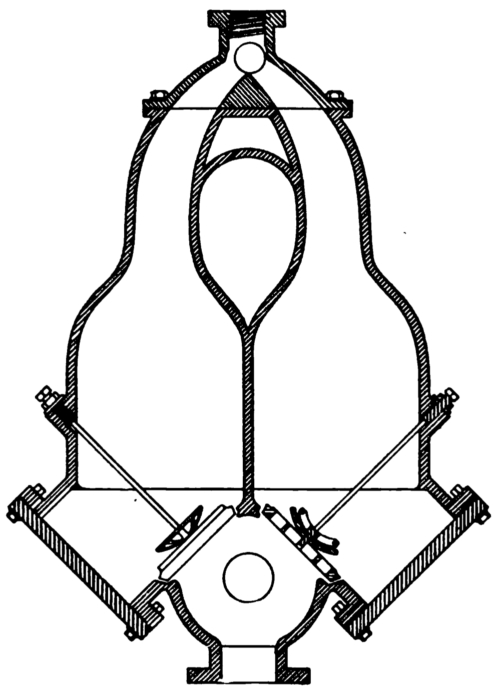


Fig. 2.

The next great step in the development of the steam engine was taken by Newcomen, who in 1705 succeeded in preventing contact between the steam and the water to be pumped, thus diminishing the amount of steam uselessly condensed. He introduced the first successful engine which used a piston working in a cylinder.

In Newcomen's engine, shown in Fig. 3, there was a horizontal lever pivoted at the center and carrying at one end a long heavy rod which connected with a pump in the mine below. A piston was hung from the other end of the lever, and worked up and down in a vertical cylinder, which was open at the top. Steam acted only on the lower side of the piston. Steam at atmospheric pressure was admitted from the boiler to the cylinder, and as the pressure was the same both above and below the piston, the falling of the heavy pump rod raised the piston. A jet of water was now passed into the cylinder to condense the steam and form a vacuum. This left the piston with atmospheric pressure above and very slight pressure below, so it was forced down and the pump rod again raised. Steam could again be admitted to the cylinder, the pump rod would fall, and so on indefinitely.

In the days of Newcomen it was very difficult to obtain good workmanship. For this reason it was often necessary to make the cylinders of wood, and even then there might be a space of one-eighth of an inch between the wall of the cylinder and the piston. In order to prevent steam from blowing through this passage, or air from leaking in when the steam was condensed, it was customary to keep a jet of water playing on the top of the piston.

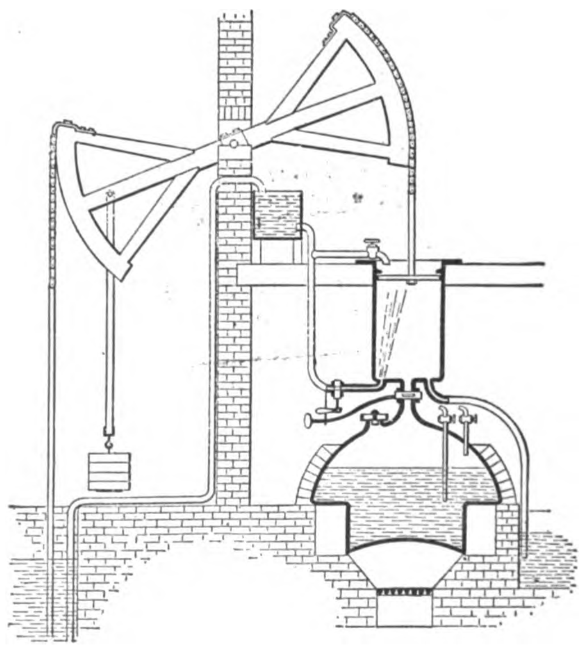
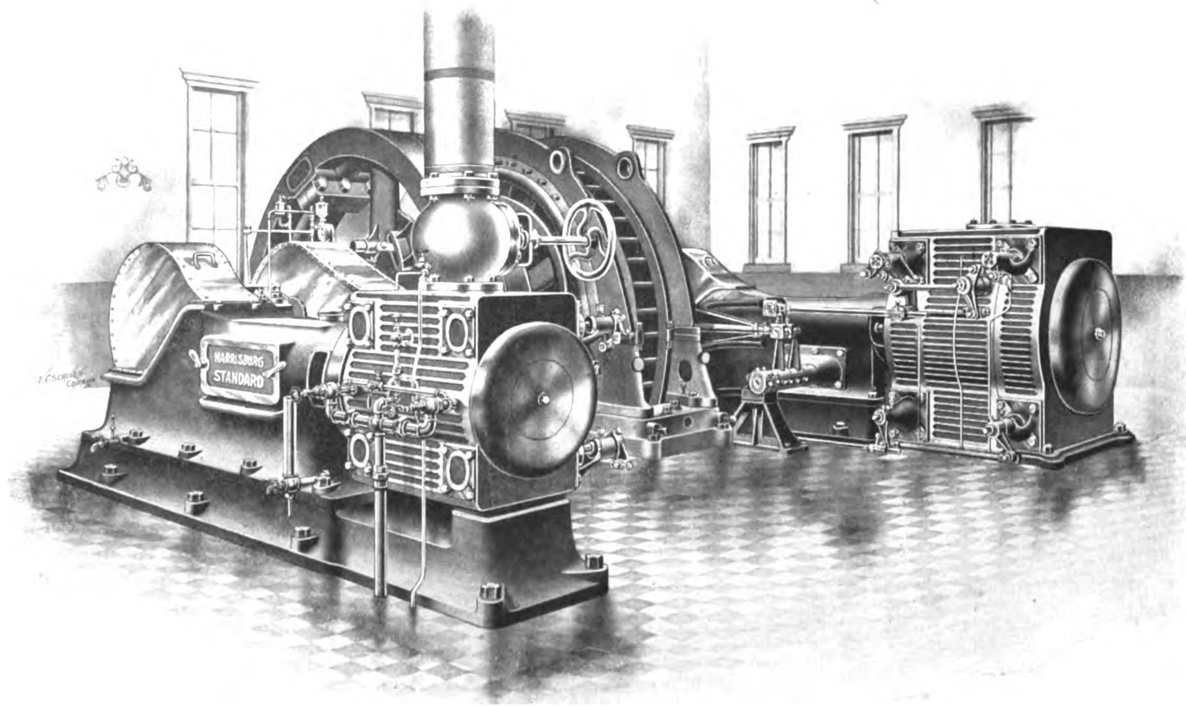


Fig. 3.

One great trouble with all these engines was that they required some one to open and close the cocks. Boys were generally employed to do this work. In order to get time to play, one of them rigged a catch at the end of a cord which was attached to the beam overhead. This did the work for him. Making the valves automatic in this way made it possible to dispense with the services of the boy and at the same time greatly increase the speed of the engine. This engine was improved slightly from time to time by different inventors and was very extensively used until



GENERAL CONSTRUCTION FLEMING CROSS COMPOUND FOUR-VALVE ENGINE DIRECT-CONNECTED STYLE, GENERAL VIEW.
Harrisburg Foundry and Machine Works.

Watt's time. Some of them are in existence today. While this engine was a success and a great improvement over its predecessors, it was still very large, wasteful and heavy, in comparison with the work done. When the cylinders were made of iron they were simply cast and not bored, thus leaving a rough, stony coating over the iron, called the skin.

In the year 1763, a small model of a Newcomen engine was taken to the shop of an instrument maker in Glasgow, Scotland, to be repaired. This instrument maker, whose name was James Watt, had been studying steam engines for some time and he became very much interested in this model. He was a man of great genius, and before he died his inventions had made the steam engine so perfect a machine that there has been but one really great improvement in it since his time; namely, compound expansion. All other improvements have been merely following in the line of his suggestions and constructing what he could not for lack of good tools.

He found that to obtain the best results it was necessary, "*First, that the temperature of the cylinder should always be the same as that of the steam which entered it; and, secondly, that when the steam was condensed it should be cooled to as low a temperature as possible.*" All improvements in steam-engine efficiency have been in the direction of a more complete realization of these two conditions.

In order to keep the cylinder nearly as hot as the entering steam, Watt no longer injected water into the cylinder to condense the steam, but used a separate vessel or condenser. He made his piston tight by using greater care in construction, so that it was not necessary to have a water seal at the top. He then covered the top of the cylinder to prevent air from cooling the piston. When this was done he could use steam above as well as below the piston; this made the engine double acting.

Also, in the effort to keep the cylinder as hot as the entering steam, he enclosed the cylinder in a larger one and filled the space between with steam. This was not often done, however, and only of late years has the steam jacket been of much advantage. He also used steam expansively, that is, the admission of steam was stopped when the piston had made a part of the stroke; the rest

of the stroke was completed by the expansion of the steam already admitted. This plan is now used in all engines that are built for economy.

Other inventions made by Watt on his steam engine were: a parallel motion, that is, an arrangement of links connecting the

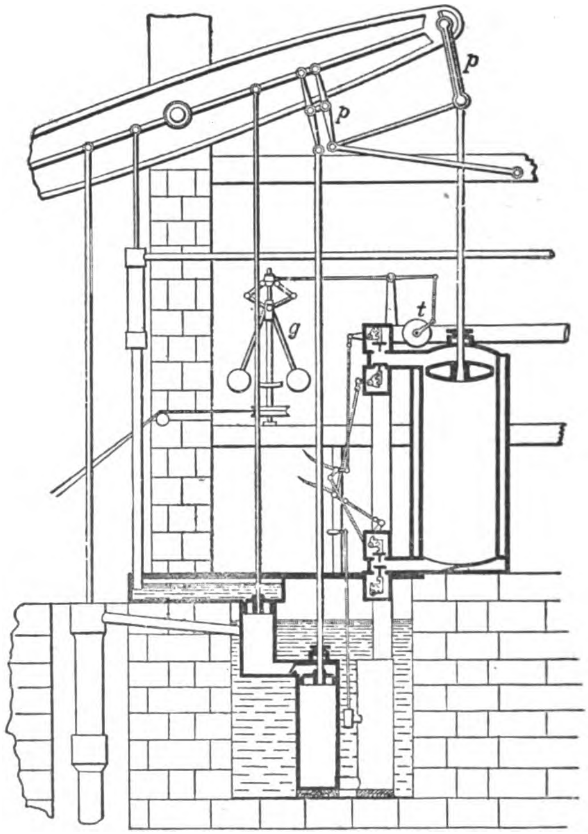


Fig. 4.

end of the piston rod with the beam of the engine in such a way as to guide the rod almost exactly in a straight line; the throttle valve, for regulating the rate of admission of steam and the centrifugal governor, which controlled the speed by acting on the throttle valve.

Watt also invented the "indicator," by means of which diagrams are made which show at all points the relation between the

pressure in the cylinder and the position of the piston at that instant. His assistant, Murdoch, invented the slide valve as a means of admitting and releasing the steam. Fig. 4 shows Watt's final engine.

Watt, like other early inventors, sold many of his engines to miners, who had been using horses to pump out the mines, and for this reason he rated his engines by the horse-power. Although this term has an historical derivation it has no real significance, and no relation whatever to the power of a horse. It is an established unit for measuring the rate at which work is done. One horse-power is the amount of work necessary to raise 33,000 pounds through one foot in one minute; and we may say that one horse-power is equal to 33,000 foot pounds per minute.

Watt saw that by using high-pressure steam he could get more work from it; but as it was not possible to make very reliable boilers he never used a pressure of more than seven pounds per square inch above the atmosphere. About the year 1800 comparatively high pressures came more into use and the *non-condensing* engine was introduced. In Watt's engine, and all those preceding his, a vacuum was produced in front of the piston by condensing the steam, and either the atmosphere or steam at atmospheric pressure pushed it through the stroke. In the non-condensing engine, using high-pressure steam, the space in front of the piston could be opened to the atmosphere at exhaust, and although the atmospheric pressure resisted its motion the pressure of the steam behind the piston was still greater than that of the air. These engines were much more simple than the condensing engines, as they required no condenser.

About this time what would now be called a compound engine was introduced by Hornblower and later by Woolf. It had two cylinders of different size. Steam was admitted into the smaller cylinder, and then passed over into the larger. The steam expanded a little in the smaller cylinder and much more in the larger one.

A great many attempts were made to build *locomotives*, but they were generally unsuccessful until George Stephenson built his engine, the "Rocket," in 1829. The principal new feature of this engine was the improved *steam blast* for increasing the

draft in the furnace and so making possible the use of a smaller boiler. Later he used the "link motion," which enabled the engine to be quickly reversed and the amount of expansion varied.

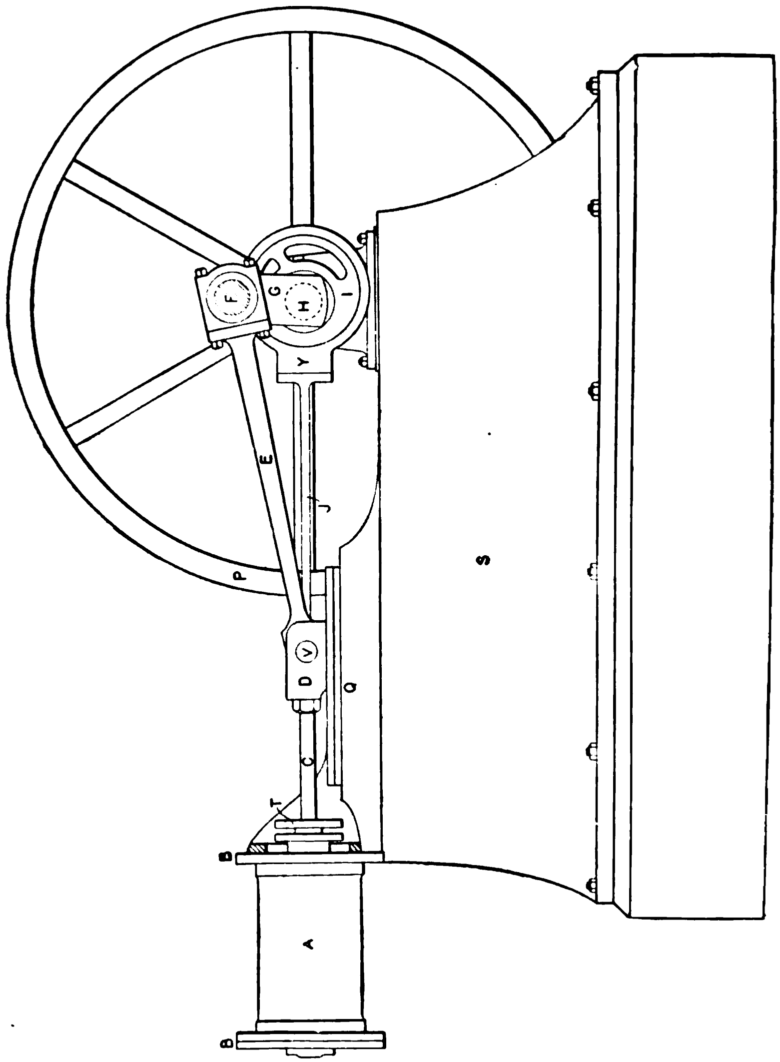


Fig. 5.

The Stephenson link motion may be seen on almost any locomotive. It is simply a device by which either of two eccentrics may be made to move the valve.

About the year 1814, Woolf introduced a compound pump-

ing engine in the mines of Cornwall, but a simpler engine was later introduced and Woolf's engine fell into disuse. This later engine became known as the Cornish Pumping Engine and was famous for many years because of its economy. It was the first engine ever built that could compare at all with modern engines in the matter of steam consumption. It consisted of a single cylinder placed under one end of a beam from the other end of which hung a heavy rod which operated a pump at the foot of the shaft. Steam was admitted on the upper side of the piston for a short portion of the stroke and allowed to expand for the remainder of the stroke. This forced the piston down, lifted the heavy pump rod and filled the pumps with water. Then communication was established between the upper and under side of the piston, exhaust occurred, and the heavy pump rod fell, lifting the piston and forcing the water out of the pumps. The cut-off was about .3 stroke, and the pump made about seven or eight complete strokes per minute with a short pause at the end of each stroke to allow the valves to close easily and the pumps to fill with water. The cylinder was jacketed. These engines needed great care and were in charge of competent men, to whom prizes were frequently given for the best efficiency, which doubtless accounts for their wonderful performance.

PARTS OF THE STEAM ENGINE.

Fig. 5 shows the elevation of a simple form of steam engine.

The Cylinder A (see plan, Fig. 6) is that part of the engine in which the piston moves back and forth. It is made of cast iron and accurately bored. Great care must be taken in this work, for any unevenness will allow steam to leak through between the piston and cylinder walls or it may even cause the piston to stick or work hard. In large engines the cylinder consists of two parts, the outer or cylinder proper and a comparatively thin cast iron liner. A space can be left between them for a steam jacket. Should the cylinder liner be damaged, it can be replaced without the expense of a new cylinder.

The Cylinder Heads B cover the ends of the cylinder and are securely bolted thereto. In the crank-end cover there is an opening for the piston rod to pass through. This opening is made

steam tight by a stuffing box which surrounds the piston rod. Sometimes the piston rod is prolonged beyond the piston and through the front cover. This extension of the piston rod is to

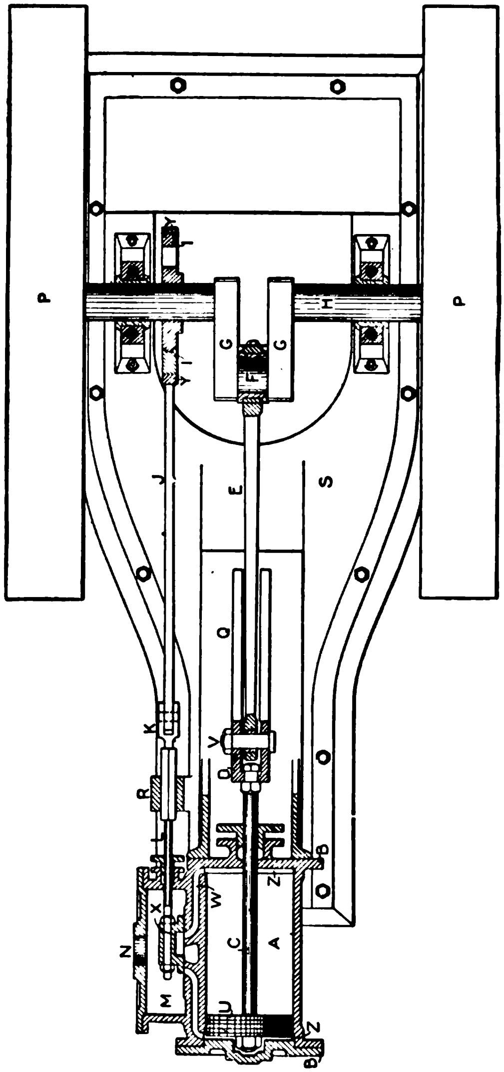


Fig. 6.

help steady the piston in a long stroke and is known as the tail rod. When a tail rod is used another stuffing box must also be provided for the head-end cover.

The Piston U, in small engines, is usually a thick disc of iron or steel, as shown in Fig. 6. It is often made conical, as shown in Fig. 7, to better withstand the steam pressure and to gain space. The piston must fit the cylinder steam tight and yet move easily. To accomplish this, one or more grooves in the piston are filled with packing (usually metallic), or spring rings may be used.

The Piston Rod C (Figs. 5 and 6) is made of steel and connects the crosshead and the piston to which it is rigidly fixed.

The Crosshead D serves to join the piston rod and connecting rod. At one end it is fastened to the piston rod, and at the other end is the wrist pin V on which the connecting rod swings. It is guided to and fro by the crosshead guides Q.

The Connecting Rod E is a steel forging from three to eight times the length of the crank, depending upon the type of engine. One end is jointed to the crosshead by the pin V, called the wrist pin, while the other encircles the crank pin and revolves with it. A detail view of one end is shown in Fig. 8; the other end is frequently similar. In some cases the small end is forked, as shown in Fig. 9.

The Crank Pin F forms the connection between the crank and connecting rod.

The Crank G, equal in length to one-half the stroke of the piston, converts the back and forth motion of the connecting rod into circular motion. It may be simply an arm, as shown in Fig. 10, or a complete disc keyed to one end of the shaft, as shown in Fig. 11. The disc is more nearly balanced than the crank.

The Shaft H transmits the rotary motion from the crank to the fly wheel P.

The Frame of the engine S is a heavy casting, which supports the cylinder and bearings. It should be securely bolted to the foundation.

The Steam Chest M receives steam directly from the boiler, and the steam passes thence through the ports W into the cylinder.

The Eccentric I is a disc keyed to the shaft so that its center and the center of the shaft do not coincide. The eccentric strap Y encircles the eccentric and imparts a reciprocating motion to the valve stem L and the eccentric rod J. This action is similar to

that of the crank and connecting rod, but exactly reversed. K is the valve stem crosshead and R its guides.

The Slide Valve X is the valve for alternately admitting

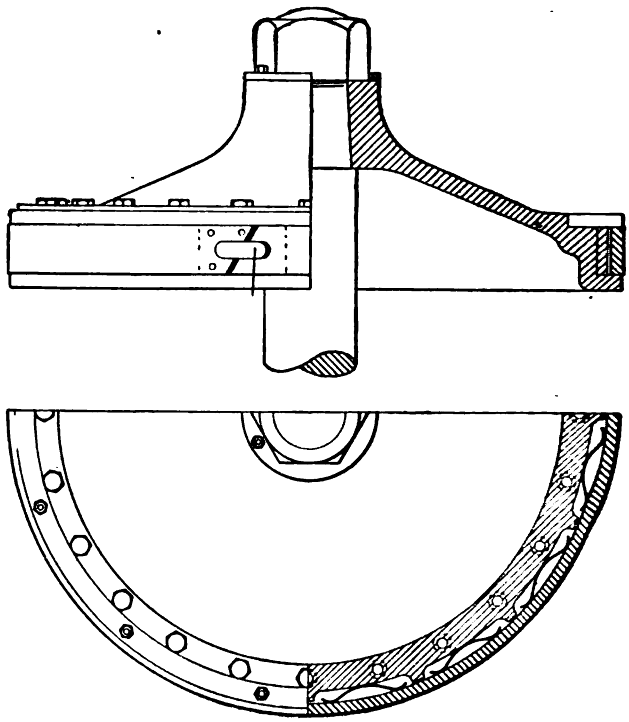


Fig. 7.

steam to the cylinder and releasing it. It has a cup-shaped cavity in its face through which the exhaust steam passes. It is situated in the steam chest and is moved by the valve gear, that is, the eccentric and the eccentric rod.

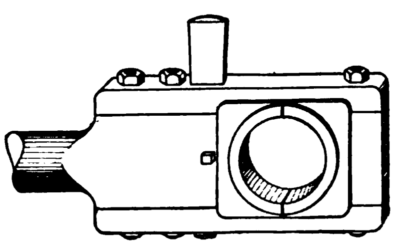


Fig. 8.

The Clearance Z is the space between the piston and the cylinder head (when the piston is at the end of the stroke), together with the volume of the steam ports. This volume must be filled with steam before the piston can start. It is usual to

express the clearance as a certain per cent of the volume swept through by the piston.

The crank may revolve in either direction. If we stand by the cylinder, facing the crank shaft, and the crank moves away from us as it passes over the shaft, we say that it is running *over*. If it moves away from us as it passes under the shaft, we say that the engine is running *under*. The action of steam in the cylinder of an engine is very complicated, and its discussion will be taken up later in the course.

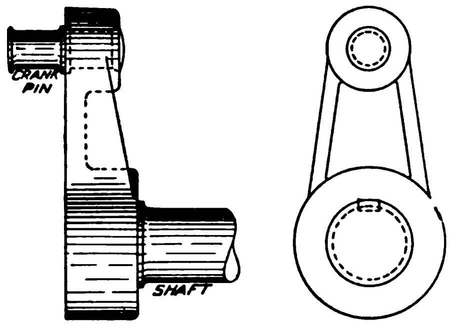


Fig. 10.

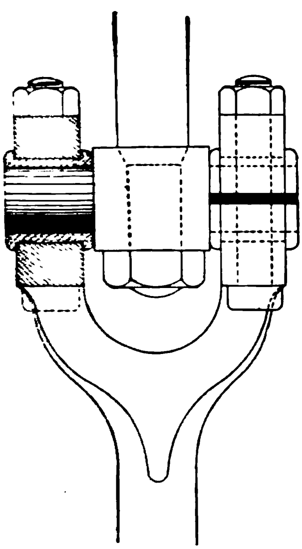


Fig. 9.

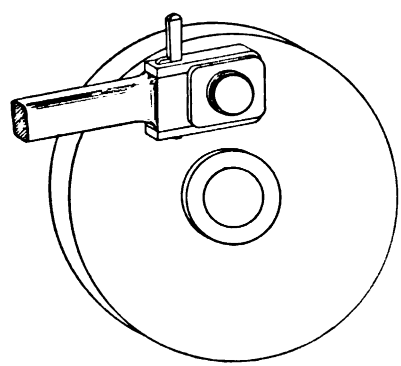


Fig. 11.

TYPES OF ENGINES.

Classification. There are so many different types of engines that it is difficult to classify them all properly. Most engines belong to several classes at one and the same time. For instance, there are condensing and non-condensing engines; there are

simple, compound, triple and quadruple expansion; there are high speed and low speed, vertical and horizontal, locomotive, stationary

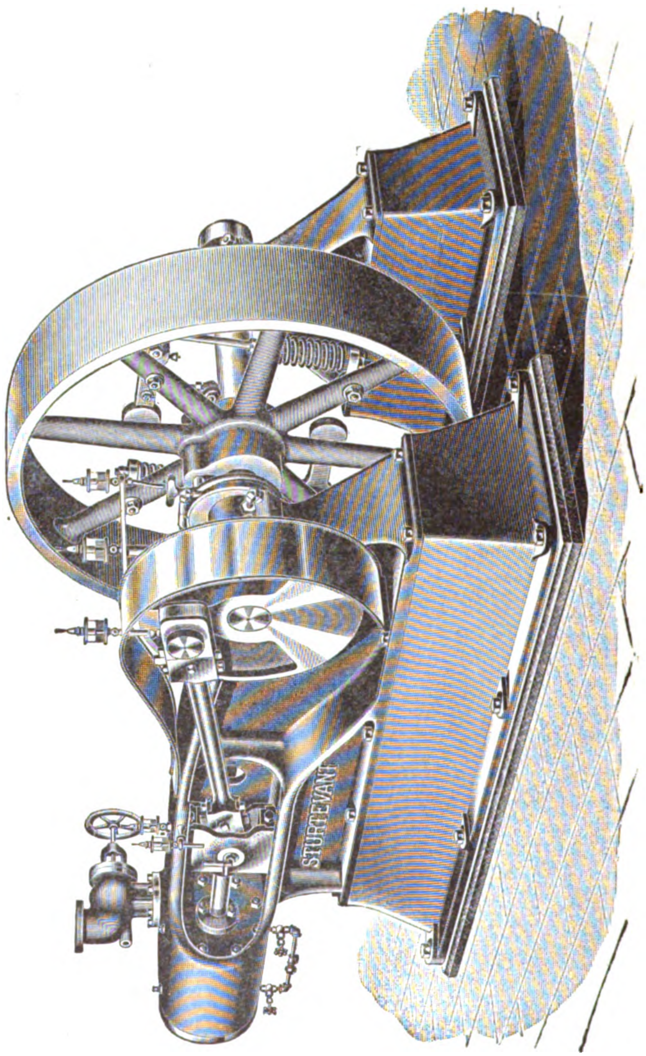


Fig. 12.

and marine, and many other classes into which these might be further subdivided.

Simple Engines. The simplest type of engine is the simple expansion. It has one cylinder and admits steam for a part of the stroke, expands it during the remainder and exhausts either into

the atmosphere or into a condenser. Simple engines (see Figs. 5 and 12) are now used only for comparatively small powers, say 100 H.P. or less, and although more extravagant of fuel than the others, may still be the most economical financially if low first cost is an important item, if they are not run continuously, or if the load fluctuates widely.

Compound Engines have two cylinders known as the high pressure and low pressure. Steam enters the smaller or high pressure cylinder and then expands until release, when it is exhausted into the larger cylinder, where the expansion is finished. The cylinders should be so proportioned that approximately the same amount of work can be done in each. The first cylinder is small, because it has the higher steam pressure, and a given weight of steam occupies less space when at high pressure. The second must be large, so that the volume at cut-off can contain all of the steam exhausted from the high.

Besides being more economical the compound has a distinct mechanical advantage. The two cranks may be set at right angles, so that when one is on dead center the other is at a position of nearly its greatest effort. This makes a dead center impossible, and gives a more uniform turning moment. Then the individual parts may be made lighter, and are thus more easily handled, but the engine is much more costly, and it is nearly twice as much work to take care of it.

When the cranks of a compound engine are at 90°, the low-pressure piston is not ready to receive steam when the high pressure exhausts, hence there must be a receiver to hold the steam until admission occurs in the low. Such engines are called *cross compound.* Fig. 13 shows one form. Sometimes instead of having the cranks at 90° they are placed together or opposite. Then the strokes begin and end together, and the high can exhaust directly into the low without a receiver. Such engines are called *Woolf engines.* A tandem compound engine, shown in Fig. 14, has both pistons on one rod, the high-pressure piston rod forming the low-pressure tail rod. Such engines are less expensive because there is but one set of reciprocating parts instead of two, but like simple engines they have the disadvantage of dead points.

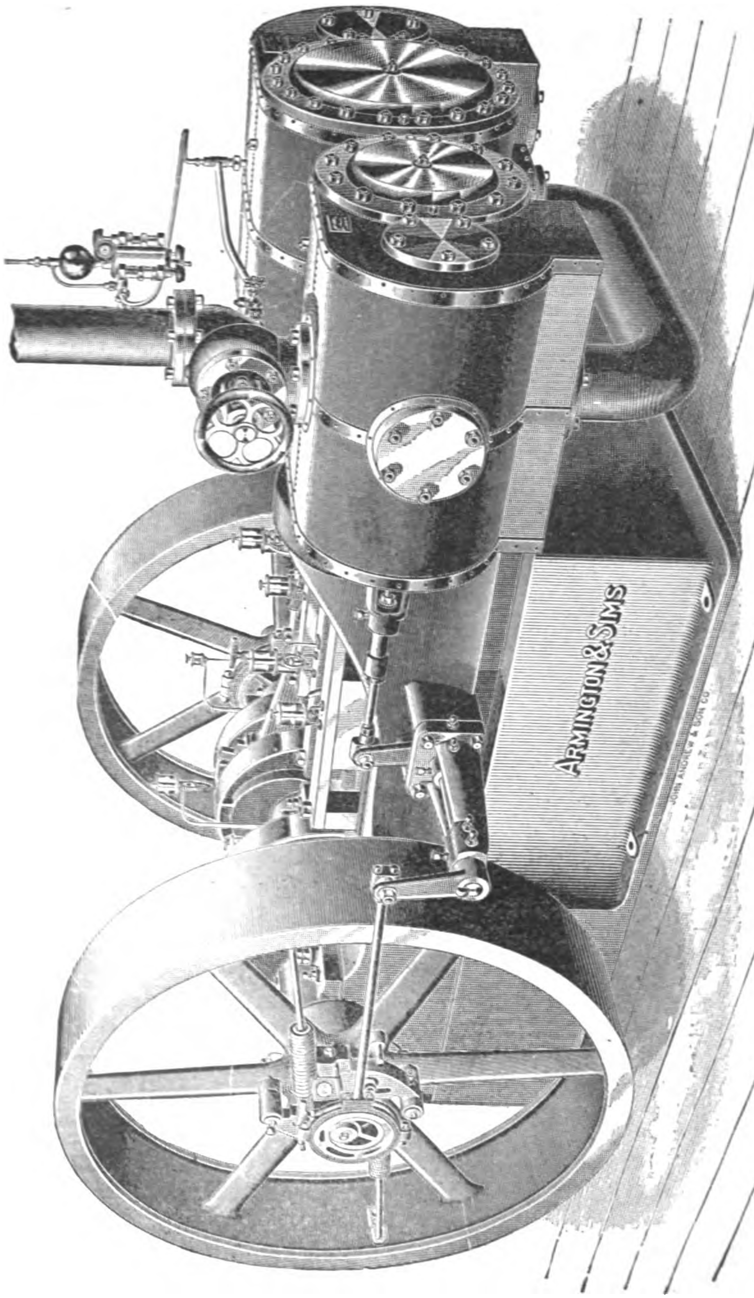


Fig. 13.

Triple Expansion Engines expand the steam in three stages instead of two. There are usually three cylinders, the high, intermediate, and low, arranged with cranks 120° apart. This gives a more uniform turning moment than a compound. Sometimes there are four cylinders to the triple, one high, one intermediate, and two low. This arrangement gives better balance and is often used in marine work.

For triple engines there must be a receiver between each two cylinders. Fig. 15 shows the essential features of a triple expansion engine.

Quadruple Engines expand their steam in four stages instead of three. Multiple-expansion engines are nearly always condensing.

Cylinder Ratios. There are several considerations to be remembered when proportioning the cylinders of multiple-expansion engines. The ratio of the cylinders should be such that each develops nearly the same power; the drop in pressure between the cylinders and receivers should be small, and the strains in the cylinders about equal.

There are many formulas in use, some simple, others involving mathematical calculation. A common rule for compound engines is to make the ratio of the cylinders equal to the square root of the total ratio of expansion. Thus if the steam has a ratio of expansion of 9, the ratio of the cylinder volumes will be $\sqrt{9} = 3$, or the low-pressure cylinder will have a volume 3 times as great as the high-pressure cylinder. If the cylinder ratio is 3, and the length of stroke is the same for both, the diameter of the low-pressure cylinder will be 1.75 times that of the high-pressure cylinder.

Another rule is to make the cylinder ratio equal to the total ratio of expansion multiplied by the fractional part of the stroke completed when cut-off occurs in the high-pressure cylinder.

Suppose the ratio of expansion is 9, as above, and that cut-off occurs at $\frac{1}{3}$ of the stroke in the high-pressure cylinder. The ratio of cylinder volumes will be $9 \times \frac{1}{3} = 3$. If cut-off occurs at $\frac{1}{2}$ the stroke, the ratio will be $9 \times \frac{1}{2} = 4.5$.

For triple expansion engines the low pressure cylinder is made large enough to develop the whole power if steam at boiler pressure is used.

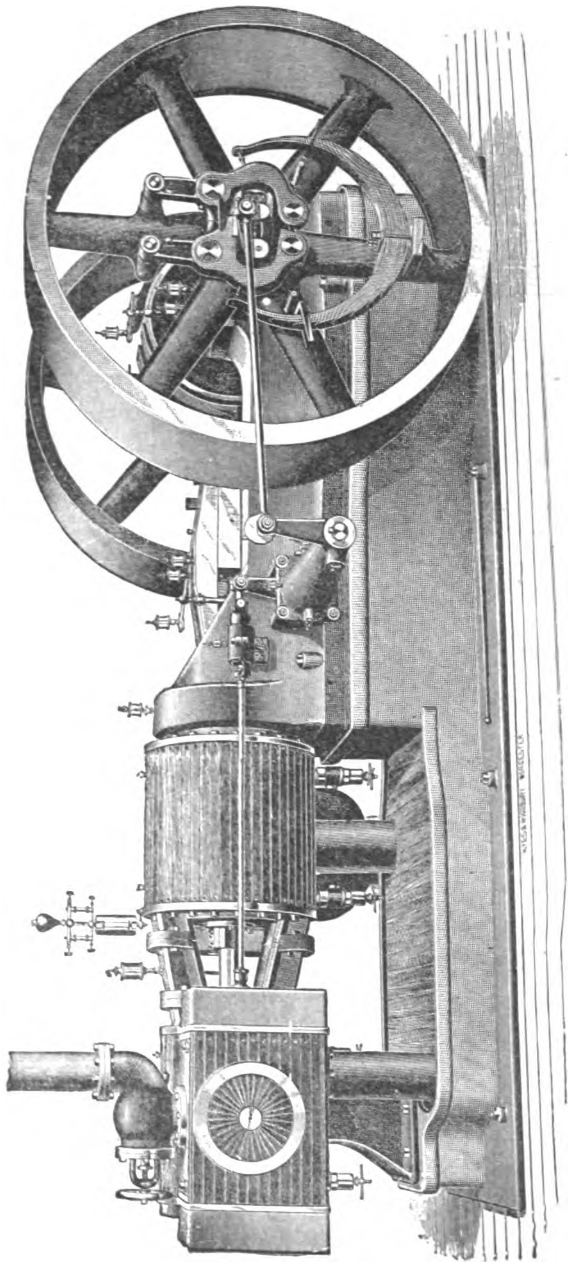


Fig. 14.

The intermediate cylinder is made approximately of a mean size between the high and the low. The area of the intermediate piston is found by dividing the area of the low by 1.1 times the square root of the ratio of the low to the high.

We may write the above thus,

$$\text{Area of high-pres. cyl.} = \frac{\text{Area of low-pres. cyl.}}{\text{Cut-off of high-pres.} \times \text{ratio of exp.}}$$

$$\text{Area of inter. cyl.} = \frac{\text{Area of low-pressure cylinder.}}{1.1 \times \sqrt{\text{ratio of low to high.}}}$$

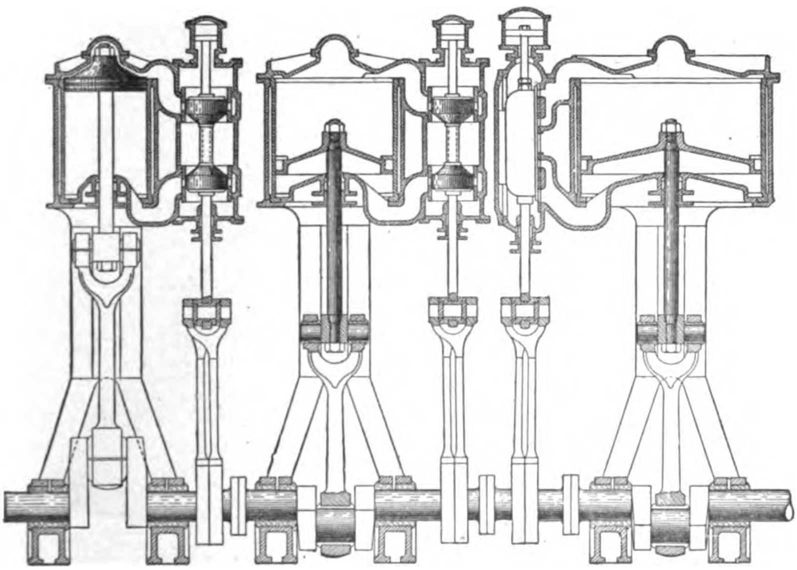


Fig. 15.

In general the volumes for triple expansion are of about the following ratios, 1 representing the volume of the high pressure cylinder:

1 : 2.25 to 2.75 : 5 to 8.

For quadruple-expansion engines the ratios are as follows:

1 : 2 to 2.33 : 4 to 5 : 7 to 12.

High Speed Engines. Of late years there has been a demand for engines of higher speeds than were formerly used. It was found desirable to run dynamo-electric machines by connecting them ***directly*** to the shaft of the engine rather than by belts as before.

This required engines running from 200 to 1,000 revolutions per minute instead of from 60 to 90 revolutions. Also for engines in

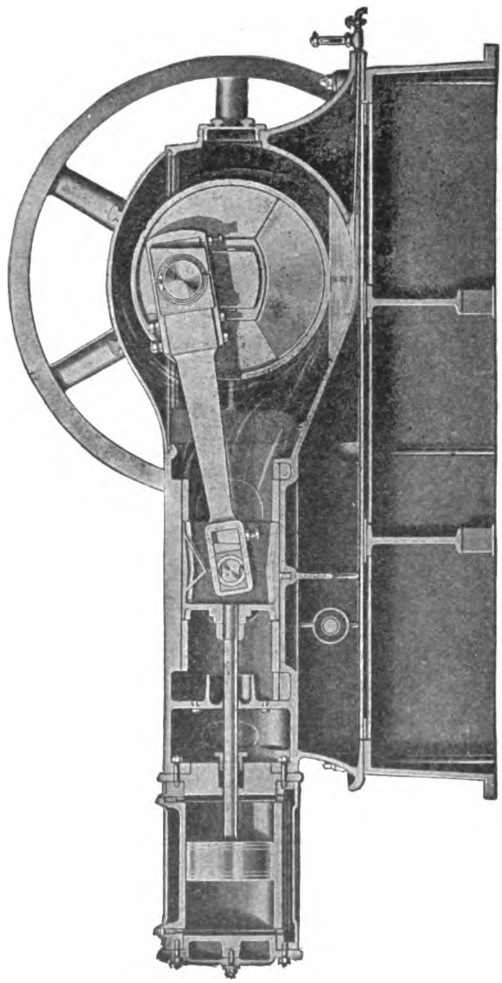
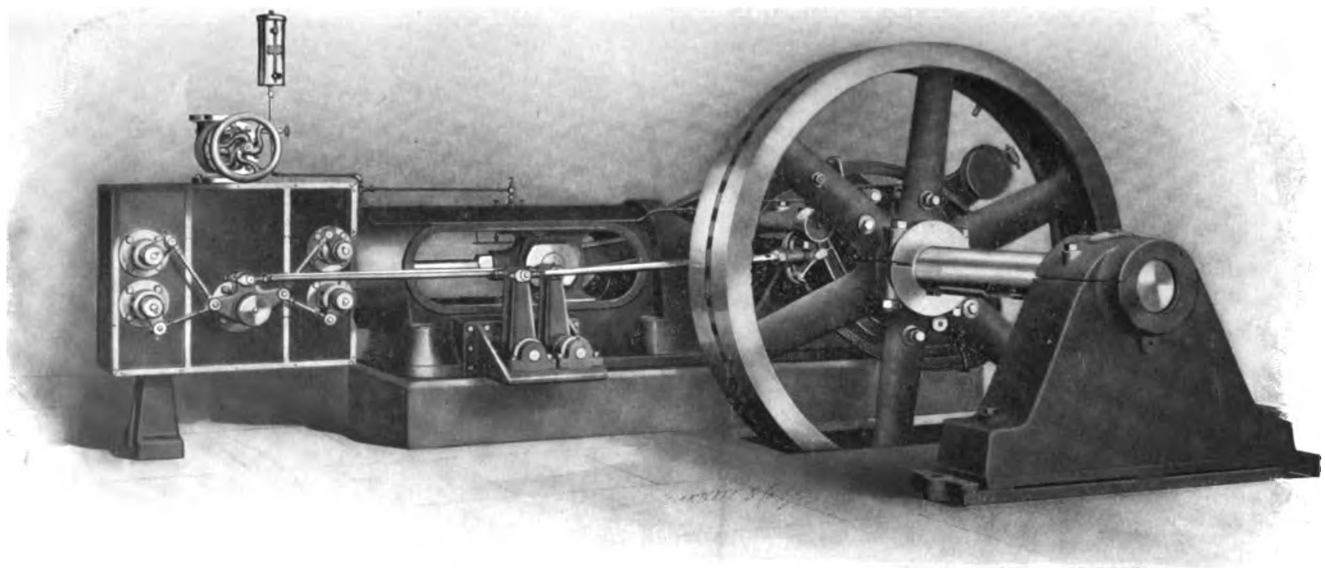


Fig. 16.

torpedo-boats, speeds as high as 400 or 500 revolutions are common.

Running at high speed requires various changes. Reciprocating parts must be made lighter to reduce the vibration, and must be



SIMPLE CORLISS VALVE ENGINE.
Ball and Wood Co.

more carefully proportioned to maintain balance. Bearings must be made very much larger to reduce the pressure in order that the friction may not be excessive and cause heating. Special care is necessary that bearings should be tight, since the least looseness will cause knocking and hammering until the bearing is ruined. Parts must be as simple as possible and so arranged as to need the least possible attention. In slow-speed engines the engineer can watch the oil cups and oil any part while it is running. But this is impossible in high-speed engines, and special means must be used to insure plenty of oil to the bearings and the cylinder.

These peculiarities of high-speed engines may be easily seen in any engine for electric lighting, for running fans, etc. It is also necessary that the speed of engines for running electric generators should be very steady, as the slightest change in the speed make the lights flicker. The fly wheels are, therefore, larger or heavier than for other types and the governors are made specially sensitive. Fig. 16 shows a horizontal high-speed engine with the working parts encased. Fig. 17 shows a vertical high speed.

For any *double-acting* engine, that is, for any engine in which the steam acts first on one side and then on the other side of the piston, the piston first pushes and then pulls on the connecting rod and crank. At each half revolution of the crank the direction of the pressure reverses. It is this change of pressure which causes the pounding if the bearings are at all loose. This is one of the greatest troubles with high-speed engines. In order to avoid these rapid reversals in pressure, *single-acting* vertical engines are used to a considerable extent. In such engines the steam is admitted only to the *head end* of the cylinder. The other end stands open. The connecting rod is in compression throughout the whole revolution instead of being first in compression and then in tension. Besides insuring that the piston shall always push, this arrangement simplifies the valves.

There are several good single-acting, high-speed engines. One of the earliest made was introduced by Brotherhood. He used three cylinders, set around the shaft 120° apart. Another well-known example is the Willans "central valve" engine. These are both English engines. A well-known American engine

of this type is the Westinghouse high-speed engine, a section of which is shown in Fig. 18.

Vertical and Horizontal Engines. At the present time the most common type of engine is the horizontal direct-acting, that

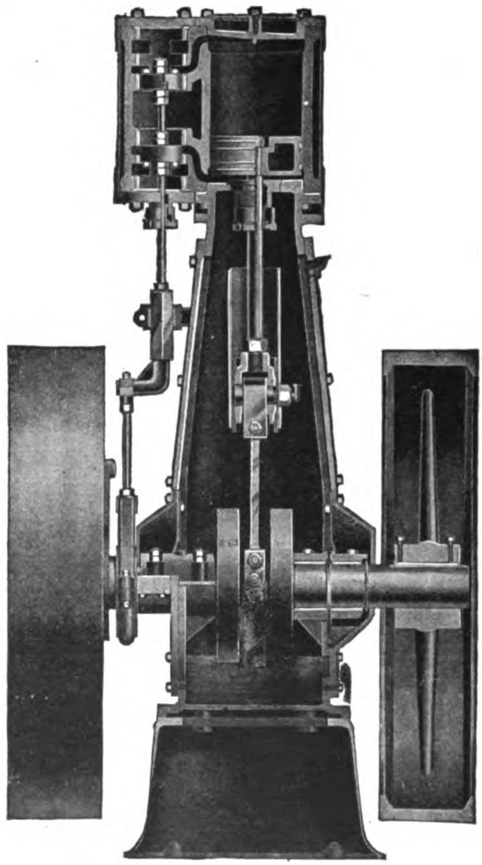


Fig. 17.

is, an engine whose cylinder is horizontal and whose piston acts on the crank through a piston rod and connecting rod. In small engines the whole is often on one bed plate. Such engines are called self contained. The cylinder is either bolted to the back of the bed plate or rests directly on it.

In marine work vertical engines are used in almost every case. The reason for this is, of course, the saving of floor space, which is so important in a vessel. This saving of space, however, is also

very important in many cases such as in crowded engine rooms of cities where land is expensive, and as there are a number of advantages which vertical engines have over horizontal, they are coming largely into use in stationary practice.

A second advantage of the vertical over the horizontal engine is the reduction of cylinder friction and unequal wear in the cylinder of the latter. In the horizontal engine the piston is generally supported by resting on the cylinder, which is gradually worn until it is no longer round. This causes leakage of steam from one side to the other. Evidently this is entirely avoided in the vertical engine.

Still another advantage of the vertical engine is the greater ease of balancing the moving parts so that there shall be no jarring or shaking. It is impossible to perfectly balance a steam engine of one or two cylinders. If it is balanced so that there is no tendency to shake sidewise, it will shake endwise; and if it is balanced endwise it will shake sidewise. The jarring is due to the back and forth motion of the reciprocating parts and the centrifugal force of the crank and connecting rod. The crank can be readily balanced by making it extend as far on one side of the shaft as it does on the other, but the piston and connecting rod are more difficult to balance. We can greatly reduce the effect of jarring if we balance the crank and make the endwise throw come in line with the foundation, which should be heavy enough to absorb the vibration transmitted. In a horizontal engine this endwise throw not being in line with the foundation will cause vibration in the engine itself.

In machines that can be anchored down to a massive foundation a state of defective balance only results in straining the parts and causing needless wear and friction at the crank-shaft bearings and elsewhere, and in communicating some tremor to the ground. The problem of balancing is of much more consequence in locomotive and marine engines.

To sum up the general advantages of vertical engines: they have less cylinder wear, they take up less floor space, and they can be better balanced. In addition to these there are certain advantages which vertical engines have for certain kinds of work.

The disadvantages of vertical engines are as follows: The

pressure on the crank-pin is greater during the *down* stroke than during the *up* stroke because, during the down stroke the weight of the reciprocating parts is added to the steam pressure, and during the up stroke this weight is subtracted.

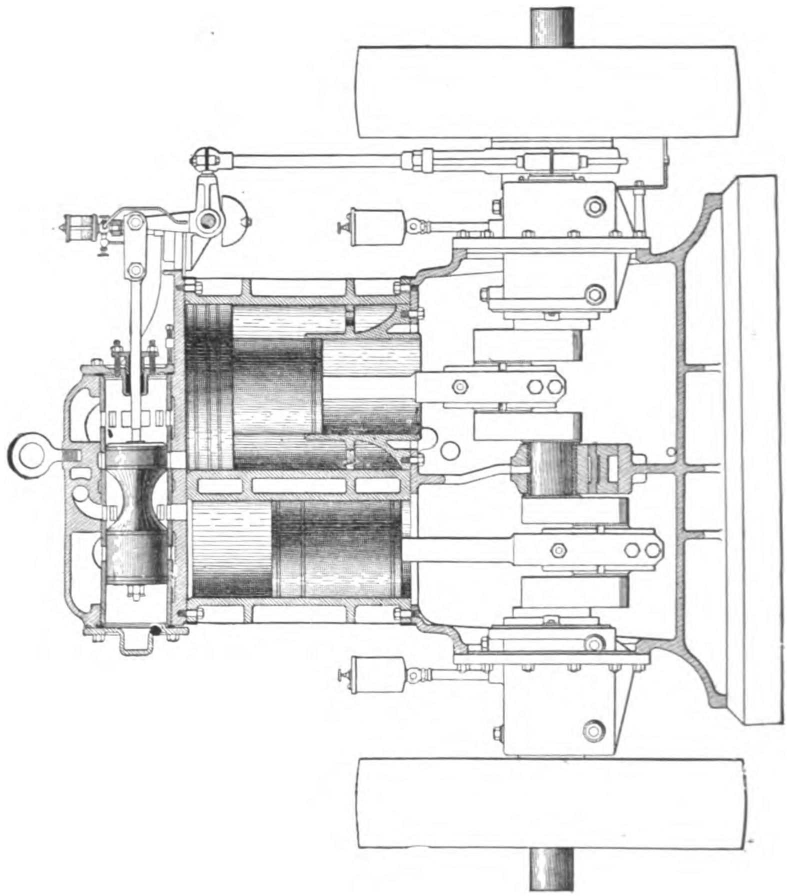


Fig. 18.

Another difficulty is that in large engines the various parts are on such different levels that they require considerable climbing. This requires more attendants and is sometimes the cause for neglect of the engine.

The foundations for vertical engines generally need to be *deeper* than those for horizontal engines. At the same time, however, they need not be as *broad*.

Marine Engines. The first steam vessels were fitted with paddle-wheels, and as beam engines were the most common, this form of engine was used. Its construction, however, was somewhat modified for this service. This arrangement of beam engine and paddle-wheel was used for many years and was applied to ocean vessels as well as to small river boats. It is still used, especially in this country, on river steamers and some coast steamers. The beam is supported by large A frames on the deck, and the engines are about on a level with the shaft.

Engines of this type take up rather more room than those now in common use, partly because of great size, and also because of the shaft and paddle-wheels. Another disadvantage is that in heavy weather, when one paddle-wheel is thrown out of water the other is deeply immersed and takes all the strain, so that there is a tendency to rack the boat. Then again if the boat is loaded heavily the paddle-blades are very deeply immersed while if light they barely touch the water. It is hard to handle the engines satisfactorily under both conditions.

The introduction of the screw propeller overcame these difficulties very largely and at the same time required a much faster running engine. At first, the increased speed was supplied by the use of spur-wheel gearing, but gradually higher speed engines were built and connected directly to the propeller shaft. It was, of course, difficult with small width at each side of the shaft to use horizontal engines, therefore various arrangements of inclined engines were used before the vertical engine was finally chosen by all as the standard form for marine work. It is only in recent years that the vertical engine has become general in naval work and in merchant steamers.

In merchant ocean steamers the common form has three cylinders set in line, fore and aft, above the shaft. The cranks are 120° apart, to give a very even turning moment. The three cylinders are worked *triple expansion*. The valves are usually piston valves on the high and intermediate, and double ported slide valves on the low. Sometimes piston valves are used on all

the cylinders. Plain slide valves are not suitable for high-pressure work of any kind.

For engines on ocean vessels it is necessary to use surface condensers in order that the same water may be used over and over again. If it were necessary to take in sea-water for the boilers they would soon become clogged with the salt and require cleaning. Surface condensers for marine work are generally made up of a large number of brass tubes of from $\frac{3}{4}$ inch to 1 inch in diameter. In some cases the cold water is forced to flow through the tubes while the steam comes in contact with the outside of the tubes.

In any marine plant there are four special pumps. The *first* is the air pump for the condenser. This is usually made large so that in case there is a leak in the condenser it can take charge of the water even if it becomes necessary to run as a jet instead of a surface condenser. The *second* is the feed pump for the boilers. The *third* is the circulating pump, which forces the current of cold water through the condenser. The last is the bilge pump, which pumps out water that gathers in the bilge of the ship by leakage or otherwise. In case of a serious leak all the pumps can be made to pump from the bilges. In some old types all these pumps were worked from the main engine; generally, however, the feed pump and the circulating pump are separate, as also the bilge pump. The circulating pump is, in many modern engine rooms, of the centrifugal type.

Locomotive Engines. Of all steam engines the most inefficient is the steam locomotive. In the first place, the boiler must be forced so hard that the products of combustion pass off at a very high temperature and consequently carry away a great deal of heat. Bits of entirely unburned or partially burned coal are drawn through and wasted.

In the second place, the boiler is exposed to great loss of heat by radiation. Although its surface is lagged, it cannot be very effectively covered, and the wind takes away a great deal of heat.

Mechanically also the locomtive is very imperfect. In most good steam engines the efficiency, that is to say, the ratio of the *effective horse-power* to the *developed horse-power is fully* $\frac{9}{10}$ or 90 per cent. In the locomotive this ratio was shown to be about 43

per cent by two independent tests. This is in part due to the special difficulties in locomotive construction, but the principal losses are those caused by radiation and the escape of heat from the stack.

As to locomotive boilers, Mr. Forney says, "The weight and dimensions of locomotive boilers are in nearly all cases determined by the limits of weight and space to which they are necessarily confined." It may be stated generally that within these limits a locomotive boiler cannot be made too large. In other words, boilers for locomotives should always be made as large as possible under the conditions that determine the weight and dimensions of the locomotives.

There are certain types of locomotives common in American practice which have special names. The eight-wheel or "American" passenger type of locomotive has four coupled driving-wheels and a four-wheeled truck in front. The "ten-wheel" type has six coupled drivers and a leading four-wheel truck. This type is used for both freight and passenger service. The "Mogul" type is used altogether for freight service; it has six coupled drivers and a two-wheel or pony truck in front. The "Consolidation" type is used for heavy freight service. It has eight coupled driving-wheels and a pony truck in front. There are also a great many special types for special purposes. In switch-yards a type of engine is used which has four or six drivers with no truck. The Forney type has four coupled driving-wheels under the engine and a four-wheel truck carrying the water-tank and fuel. This type is used on elevated roads largely. "Decapod" engines are a type used for heavy freight service, having ten coupled driving-wheels and a two-wheel truck in front. A tank engine is one which carries the feed water in tanks on the engine itself instead of in the tender, as in other engines. The various different forms are too numerous even to name.

There has been some effort made to introduce compounding in locomotive practice. It has in some cases been very successful, especially for express trains. A committee of the American Railway Master Mechanics Association says of compounding:

"(*a*) It has achieved a saving in the fuel burnt, averaging 18 per cent at reasonable boiler pressures.

(*b*) It has lessened the amount of water to be handle.

(*c*) The tender can, therefore, be reduced in size and weight.

(*d*) It has increased the possibilities of speed beyond sixty miles per hour, without unduly straining the engine.

(*e*) It has increased the haulage power at full speed.

(*f*) In some classes of engines it has increased the starting power.

(*g*) It has lessened the valve friction per horse-power developed."

A number of other reasons are given in their report.

In opposition to this may be mentioned the extra first cost of the engine and the cost of maintaining a more complicated machine. It is much more work to keep it in repair and many engineers are of the opinion that the saving in fuel is only sufficient to offset these extra expenses. If the engine is running under steady load, the compounding will effect a great saving; but in many parts of the country the load varies constantly, due to grades in the road.

We shall learn later that a compound engine cannot work efficiently under light load. If the grades are first up and then down, the simple engine is the more economical. For a steady up-grade the compound is more economical, as it can be run steadily under full load. This is especially true in mountain districts, where the long up-grades and scarcity of fuel and water make ideal conditions for compound locomotives. Through freight service probably offers the widest field for success with these engines.

It has already been said that it is difficult to balance an engine completely. This defect is very much greater in locomotives than in stationary engines. Lack of balance in a locomotive results in serious pounding of the track. Also there is danger of flattening and breaking the wheels, and the rails may be seriously damaged.

Pumping Engines. The first steam engines built were pumping engines and today the most economical engines are those built for this work.

In pumping engines it is not absolutely necessary to have a revolving shaft. All that is required is that the piston in the pump cylinder shall be driven back and forth with a plain recipro-

cating motion which may be exactly like that of the steam piston. For this reason, in early pumping engines and also in many modern engines, the reciprocating motion of the steam piston is applied directly, or through a beam, to produce the reciprocating motion of the pump piston or plunger without the use of any revolving part. Frequently, however, it is desirable to use a fly wheel so that the steam may be used expansively, and in these cases, of course, a revolving shaft must be used. Fig. 19 shows a power pump.

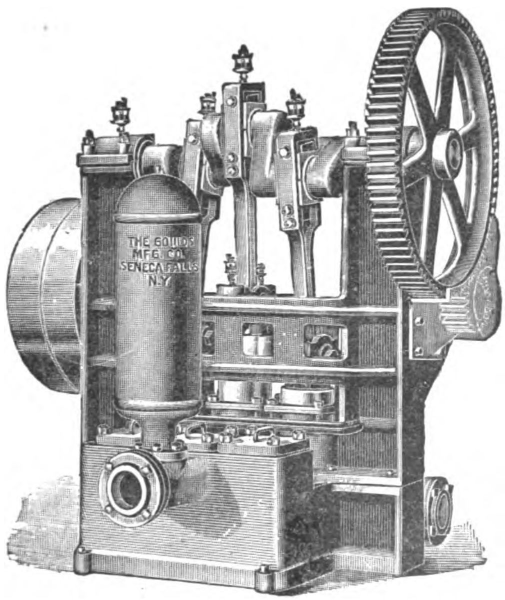


Fig 19.

For deep-well or mine pumping, the cylinders are often set in a vertical position directly over the pump cylinder. The piston rod extends from the steam cylinder directly below to the pump plunger. Sometimes it is possible to use steam expansively in these pumps by reason of the weight of the reciprocating parts. When the weight is sufficient, the steam can be cut off before the end of the stroke and the momentum of the parts will be enough to just finish the stroke, consequently these pumps are sometimes compounded. They are possible only in pumping from very deep wells.

Direct-acting Steam Pumps. Fly wheel pumps have one disadvantage, if run too slowly the momentum of the fly wheel is not sufficient to carry it by the dead centers; if run too fast the fly wheel is in danger of bursting. A fly-wheel pump can be made to discharge a small amount of water by means of a by-pass valve, but of course it then runs at a disadvantage.

The direct-acting steam pump shown in Fig. 20 has the steam piston at one end of a rod and the water piston at the other end. The steam pressure acts directly on the piston; no fly wheel is used, and since the reciprocating parts are comparatively light, and there is no revolving mass to carry by the dead points, it is evident that in the ordinary form there can be no expansion of steam. The pump is inexpensive and gives a positive action. It uses a great quantity of steam relatively, but for small work the absolute amount is not very great. Even in larger engines the lighter foundations that are possible and the slight first cost are frequently controlling features.

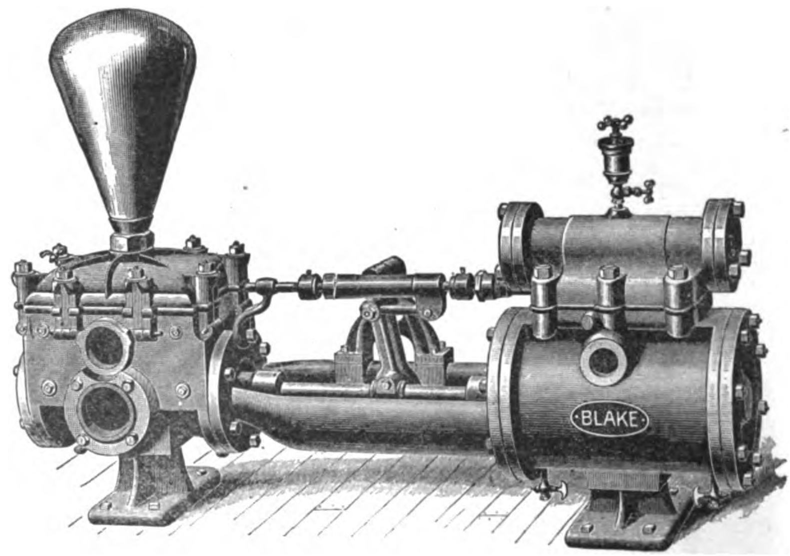


Fig. 20.

A rocker or bell-crank lever on the piston rod moves the steam valve and admits steam to the other side of the piston while opening the first side to exhaust. In large pumps of this kind, and even in some small ones, this motion merely admits steam to a small auxiliary piston which then moves the main steam valve by steam pressure. Some pumps operate the steam valve by means of a tappet instead of a rocker and bell-crank lever.

There have been various devices tried for using steam expansively in these direct-acting pumps without the use of a fly-wheel.

In order to do this it is necessary to provide some means of storing energy during the early part of the stroke and returning it during the latter part, when, owing to the expansion, the pressure of the steam is less. One such device is as follows: a crosshead A, (Fig. 21) fixed to the piston rod is connected to the plungers of a pair of oscillating cylinders B B, which contain water and communicate with a reservoir full of air compressed to about 300 pounds per square inch. When the stroke (which takes place in the direction of the arrow) begins, these plungers are first forced in, and hence work is at first done on the main piston rod, through the compensating cylinders B B, on the compressed air in the reservoir. This continues until the crosshead has advanced so that the oscillating cylinders stand at right angles to the line of stroke. Then for the remainder of the stroke their plungers

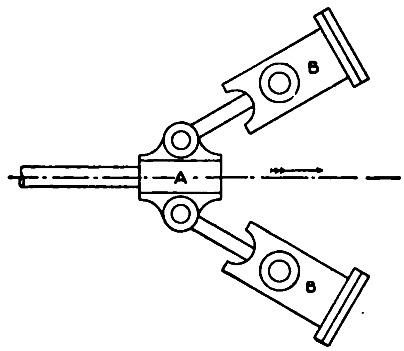


Fig. 21.

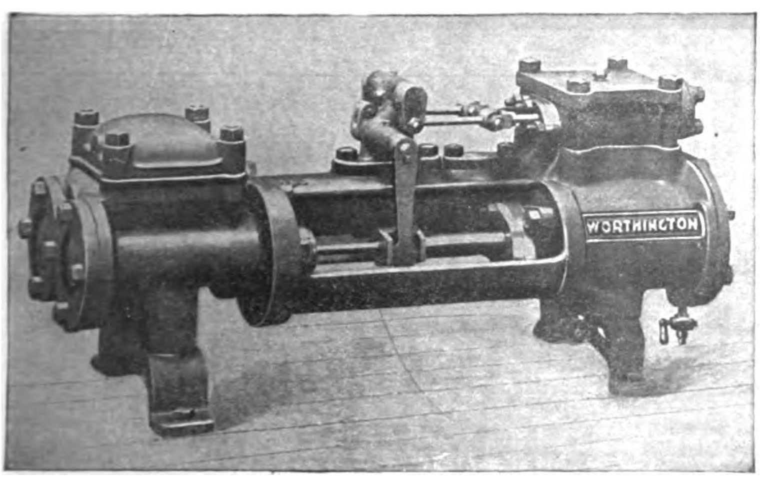


Fig. 22.

assist in driving the main piston, and the compressed air gives out the energy which it stored in the earlier portion.

The Duplex steam pump consists simply of two direct-acting steam pumps placed side by side, as shown in Fig. 22. On the piston rod on one side is a bell-crank lever which operates the valve of the other pump. On the further piston rod is a rocker arm which moves the valves of the first pump. There must be a rocker on one side and a bell-crank lever on the other because of the relative motion of the valves and pistons. The first piston, as it goes forward, must use a rocker because it draws the second valve back. The second piston, as it goes back, must use a bell-crank lever because it must push the first valve back in the same direction as its own motion. The two pistons are made to work a half-stroke apart. Thus one begins its stroke when the other is in the

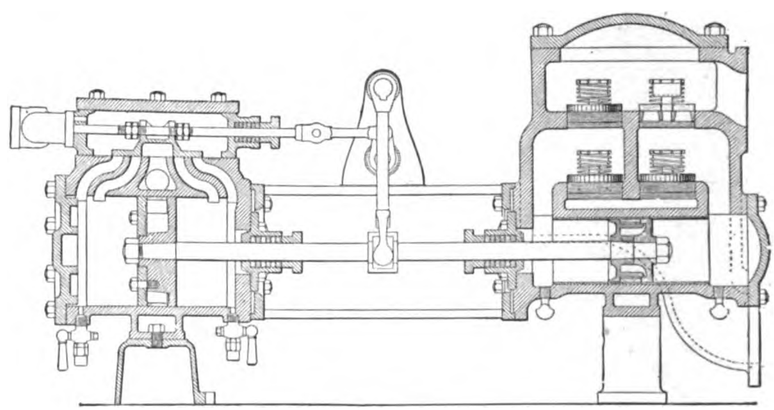


Fig. 23.

middle. In this way a steadier flow of water is obtained, for both pumps discharge into the same delivery pipe. The pumps may be made compound. A sectional view of the pump is shown in Fig. 23.

Corliss Engines. In large engines a common way of regulating the steam supply is by changing automatically the point in the stroke of the piston at which the steam is cut off. This is frequently accomplished by using some trip gear similar to the one first introduced by Geo. Corliss. These gears are called Corliss gears. In the Corliss gear there is a separate admission valve and a separate exhaust valve for each end of the cylinder, as shown in Fig. 24. The exhaust valves are opened and closed by

the motion of rods or cranks connected to them. The admission valves are opened in the same way, but they snap shut by themselves when the piston has reached a certain point of its stroke. This point will vary with the position of the governor, which in turn depends on the speed of the engine. These Corliss engines cannot be run at high speed because the trip gear requires some time to act.

The valves of Corliss engines turn in hollow cylindrical seats which extend across the cylinders. A wrist plate which turns on

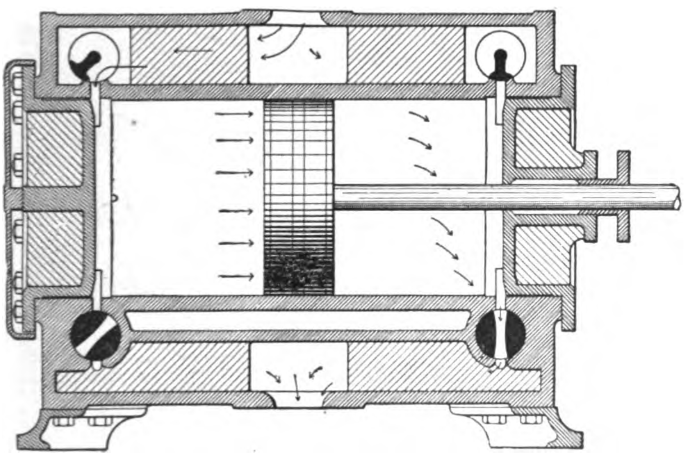


Fig. 24.

a pin on the outside of the cylinder receives a motion of oscillation from an eccentric and opens the valves by means of the rod connections. When the piston has reached a point where the steam should be cut off, the trip gear is held in such a position by the governor that it releases the valve, which now springs shut under the action of the dash-pot. The admission valve to the other side of the cylinder is controlled in exactly the same way.

The admission valves are generally placed at the top and the exhaust valves at the bottom of the cylinder. Any water which may be formed by steam condensing can readily drain off by this arrangement. There are a great many modifications of the Corliss gear. Fig. 25 is a Harris Corliss Engine.

The advantage of the Corliss gear is the great range through

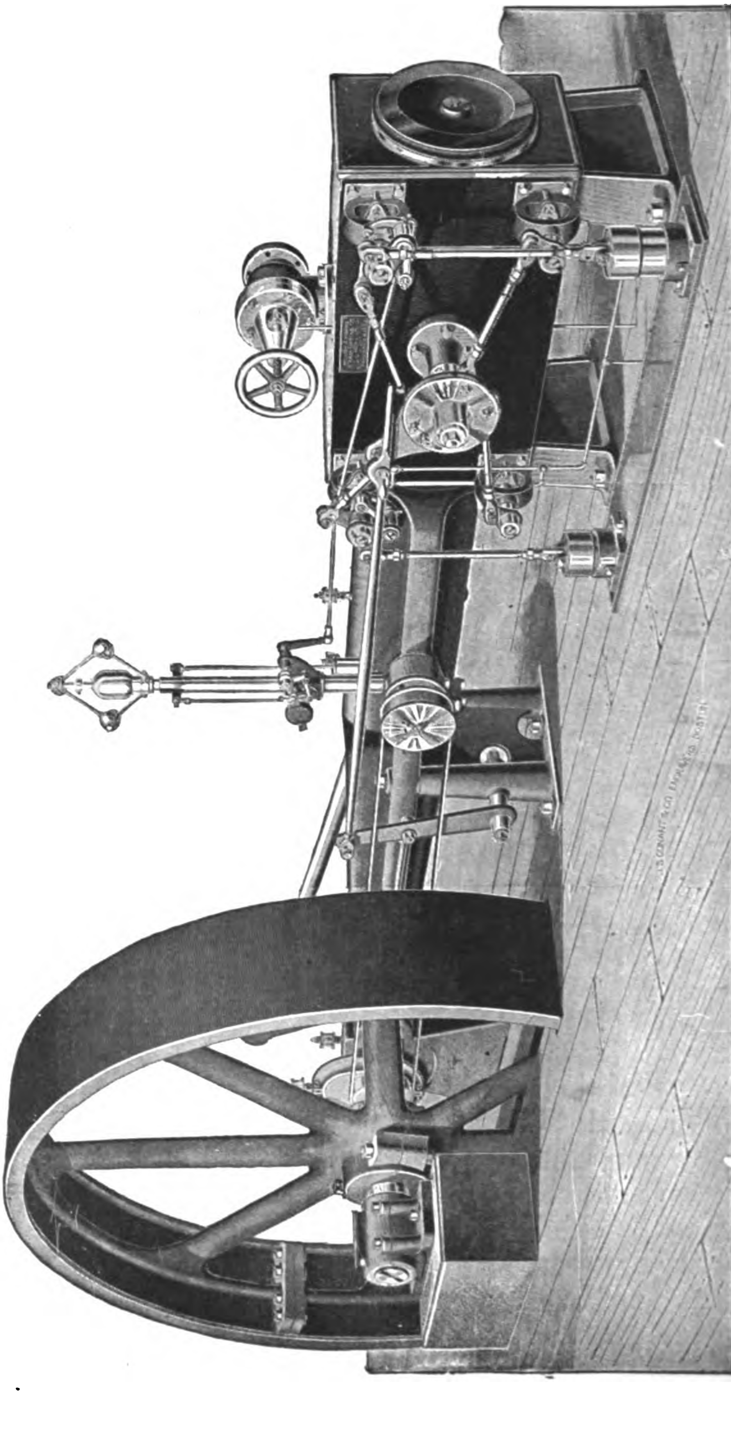


Fig. 25.

which the cut-off can be varied, from very early to very late in the stroke. Another great advantage is the quick action which reduces wire-drawing. To understand fully the loss caused by wire-drawing requires a knowledge of higher mathematics.

CONDENSERS.

When low-pressure steam is cooled it gives up its latent heat; that is, it changes from a vapor to a liquid. We know that a liquid occupies much less space than an equal weight of vapor; hence, by changing the steam to water the pressure is greatly reduced. By cooling the steam in the cylinder in front of the piston the back pressure, or resistance, is decreased. This reduces the pressure necessary to push the piston through the stroke, therefore less steam is required to do the work. This cooling is accomplished by some form of condenser.

There are two types of condensers, surface and jet. A surface condenser is one in which the steam passes through pipes surrounded by water or the water flows through pipes surrounded by steam. In the jet condenser the steam is condensed by coming in contact with cold water, which enters as spray. In both types the steam is condensed to water and a partial vacuum is formed, because water occupies much less space than does an equal weight of steam. If it were not for the air in the entering steam there would be an almost perfect vacuum. For this reason every condenser is fitted with an air pump to remove this air and the condensed steam.

Surface Condensers. The condenser shown in section in Fig. 26 is a common form of the surface type, in which the air pump and circulating pump are both direct acting and are operated by the same steam cylinder. The cold condensing water is drawn from the supply into the circulating or water pump. This pump forces the water up through the valves and water inlet to the condenser. It flows, as indicated by the arrows, through the inner tubes of the lower section, then back through the space between the inner and outer tubes. The water then passes upward and through the upper section, as it did in the lower. It then passes out of the condenser through the water outlet, taking with it the heat it has received from the steam.

The exhaust steam from the engine enters at the exhaust inlet and comes in contact with the perforated plate, which scatters it among the tubes. This method protects the upper tubing from the effect of direct contact with the exhaust steam. The steam expanding in the condenser comes in contact with the cool tubes,

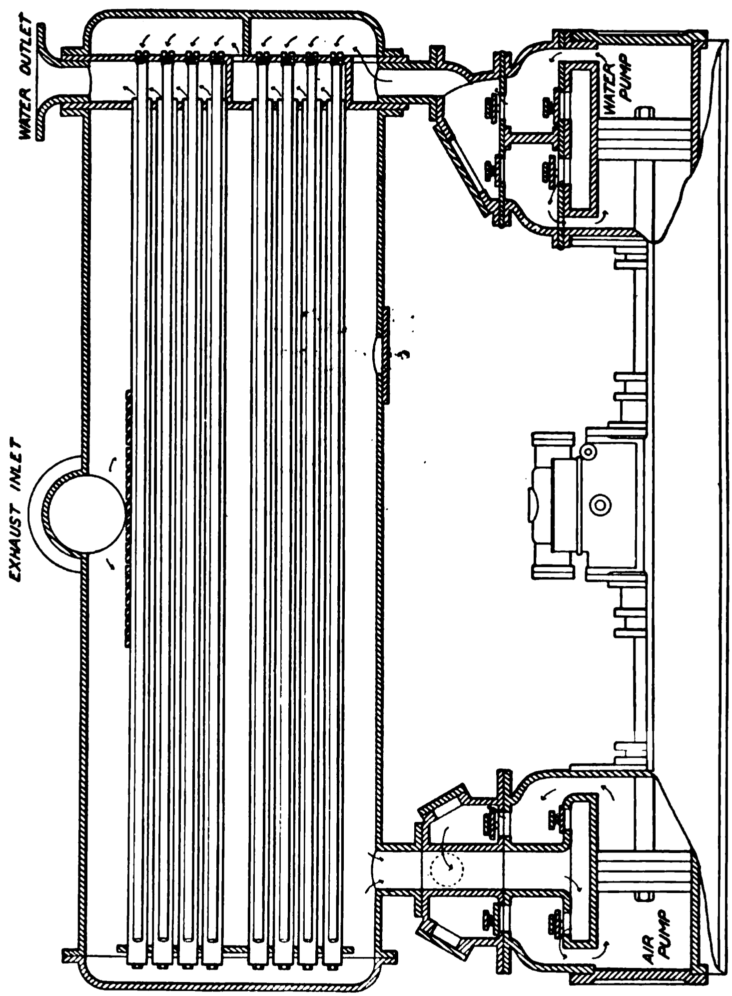
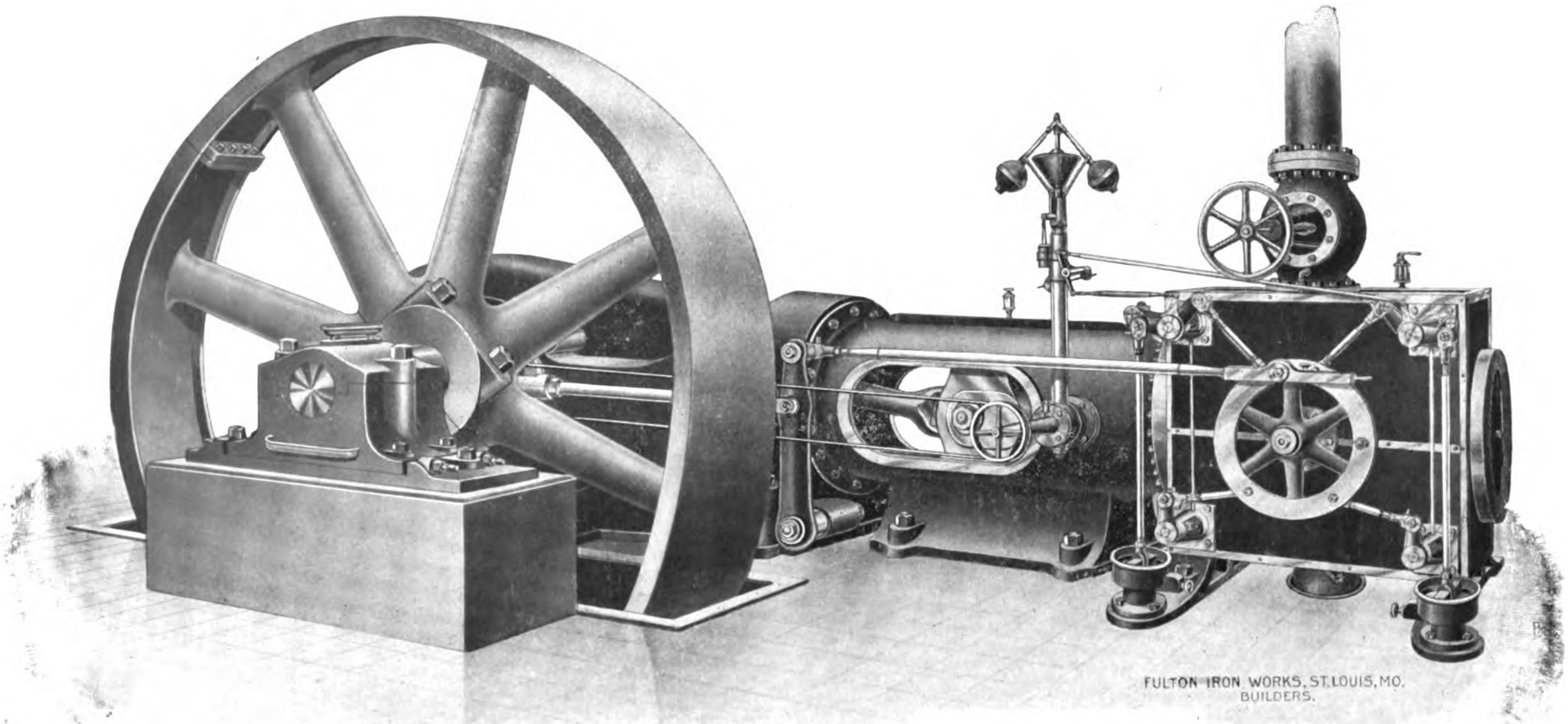


Fig. 26.

through which cold water is circulating, and condenses. The air pump draws the air and condensed steam out of the condenser and thus maintains a partial vacuum. This causes the exhaust steam in the engine cylinder to be drawn into the condenser.



SINGLE CYLINDER HEAVY DUTY CORLISS ENGINE.
Fulton Iron Works.

The condensed exhaust steam collects at the bottom of the condenser, is drawn into the air pump cylinder and is discharged while heated to the hot well of the boiler. The use of this hot water as feed water is a considerable saving; but the great advantage of the condenser is the reduction in back pressure.

Hot water cannot be used by an ordinary pump as well as cold water because of the pressure of the vapor which arises from the hot water. In the condenser shown, the water and air pumps are run by the piston in the steam cylinder. Sometimes these pumps are connected to the main engine and receive motion from the shaft or crosshead.

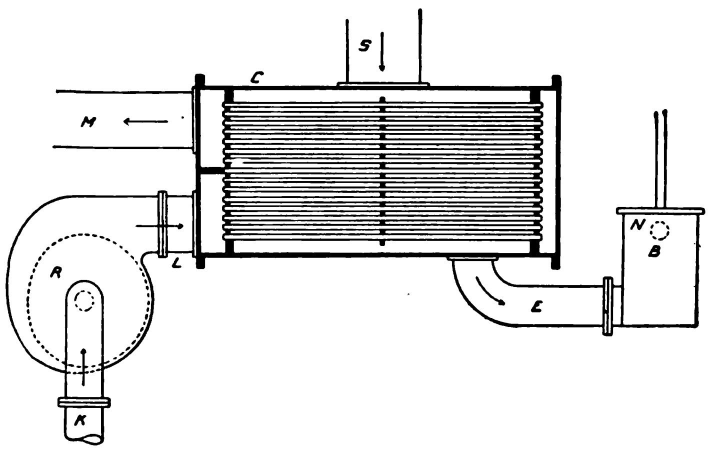


Fig. 27.

The general arrangement of the surface condenser with the necessary pumps is shown in Fig. 27. The cooling water enters through the pipe K, and flows to the circulating pump R, which forces the water into the condenser through the pipe L. In case the water enters the condenser under pressure from city mains no circulating pump is necessary. After flowing through the tubes it leaves the condenser by means of the exit M, and flows away. Exhaust steam enters at S, and is condensed by coming in contact with the cold tubes; the water (condensed steam) then falls to the bottom of the condenser and flows to the air pump B by the pipe E. The air pump removes the air, vapor and condensed steam from the condenser and forces it through the pipe N into the hot well, from which it goes to the boilers or to the feed tank.

The circulating pump, when separate from the condenser, is usually of the centrifugal type. This pump consists of a fan or wheel which is made up of a central web or hub, and arms or vanes. This pump is shown in Fig. 28. The vanes are curved, and as the water is drawn in at the central part the vanes throw it off at the circumference. A suitable casing directs the flow. This type of pump is advantageous because there are no valves to get out of order, and as the lift is little, if any, the pump will discharge a large volume of water in a nearly constant stream. The circulating pump is usually so placed that the water flows to it under a slight head. The pump is driven by an independent engine so that the circulating water may cool the condenser even if the main engine is not working.

The centrifugal pump works more smoothly and with less trouble than an ordinary force pump, because it is not reciprocating and it has no valves.

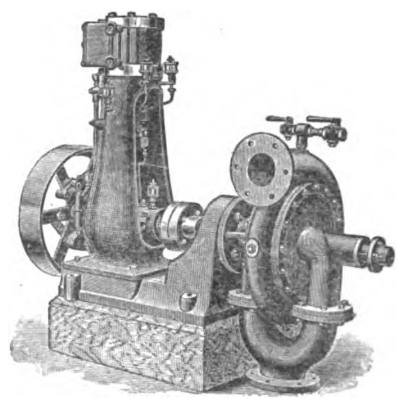


Fig. 28.

Jet Condensers. Fig. 29 shows the longitudinal section of an independent jet condenser with the pump. The cold water used to condense the steam enters at A, passes down the spray pipe B, and is broken into a fine spray by means of the spray cone C. This action insures a rapid and thorough mixing of the steam and water and consequently a rapid condensation. The exhaust steam enters at D, with a comparatively high velocity, which is imparted to the water. The whole mixture of water, steam and vapor passes at high velocity through the conical chamber E to the pump cylinder F. The pump forces this water to the pipe G. The spray cone is adjusted by the stem which passes through the stuffing box at the top of the condenser. The valves are shown at H and K. The steam end of the pump is at L. Motion of the valve is produced by the rocker arm J.

In Fig. 30 a jet condenser is shown connected to a stationary engine and boiler. The exhaust pipe leads from the engine to the

condenser, the arrows indicating the direction of flow. Cold water enters the condenser through a pipe connected to the well. Part of the mixture of exhaust steam and condensed water goes to the feed-water heater, which is kept nearly full; the rest passes to the sewer. The heater is placed a little above the feed pump, so that the water will enter the pump under a slight head, because the pump cannot raise water warmed by exhaust steam as readily as cold water.

The surface condenser is used almost universally in marine practice. Its first cost is more than that of the jet condenser and it requires more condensing water, but it allows only the condensed steam to return to the boiler. It is also used in stationary work when the condensing water is very impure. The jet condenser is not adapted for marine work, as it pumps both the condensing water and the condensed steam to the hot well. Hence, if salt water or water containing lime is used, it will enter the boiler and form sediment and scale. This type is used

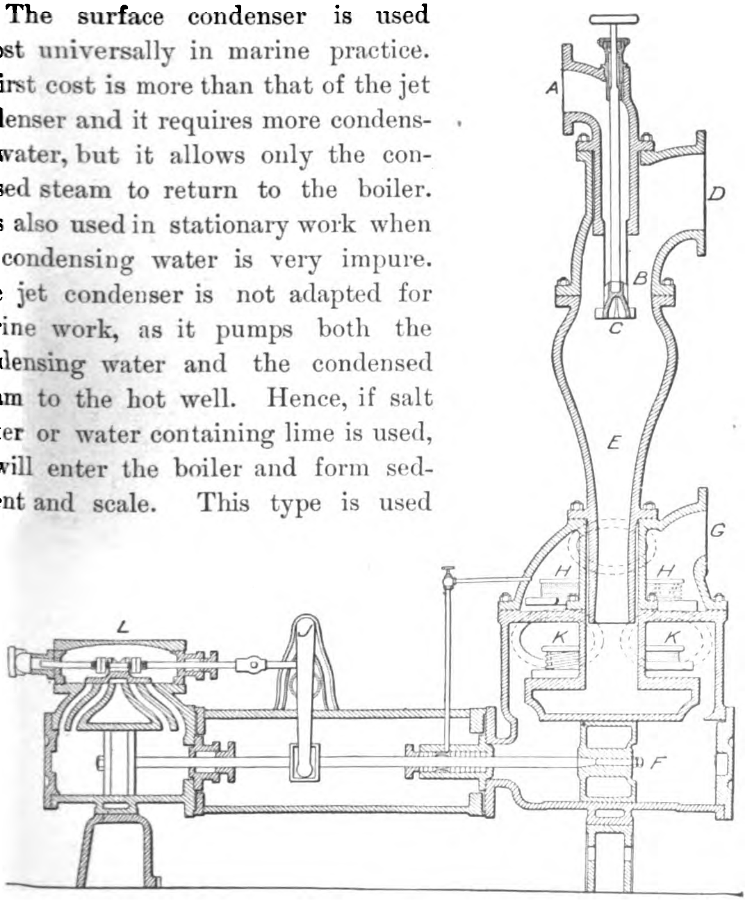


Fig. 29.

where fresh and moderately pure water is available.

It has been mentioned before that Watt always condensed the exhaust steam from his engines, and that when higher pres-

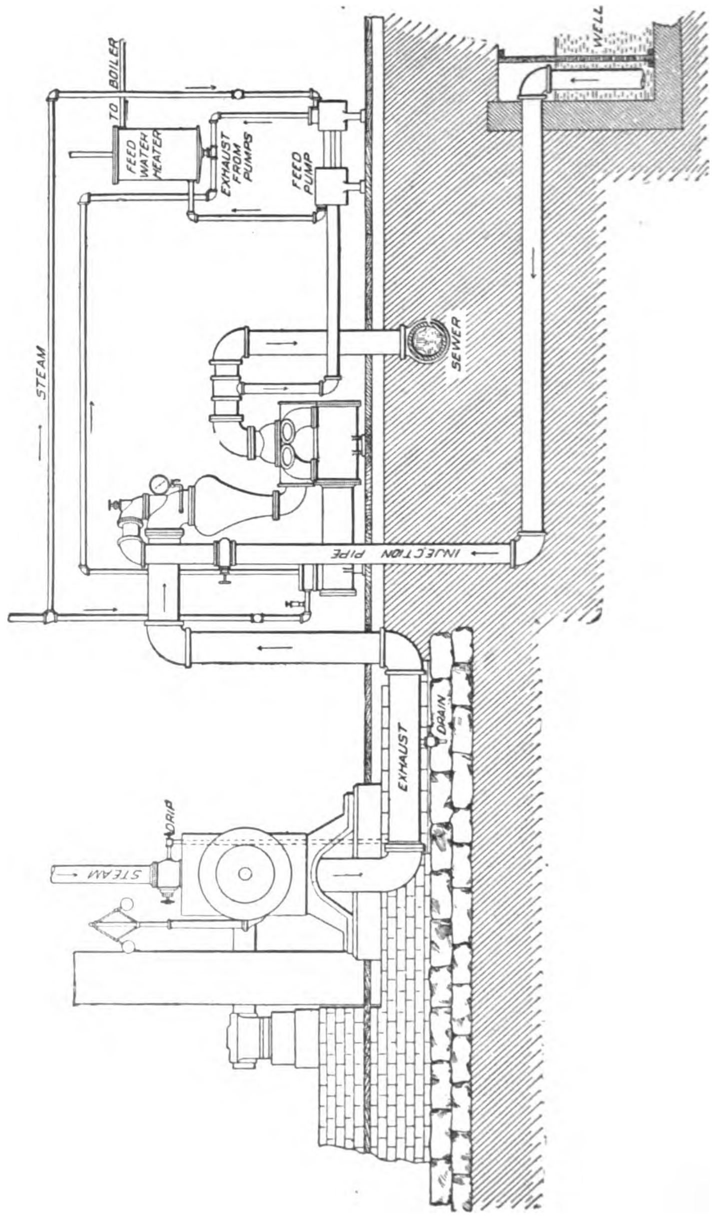

TO BOILER
FEED WATER HEATER
EXHAUST FROM PUMPS
FEED PUMP
STEAM
SEWER
INJECTION PIPE
WELL
EXHAUST
DRAIN
DRIP
STEAM

Fig. 30.

sures came into use some makers let the steam discharge into the atmosphere. This leads to the distinction between condensing and noncondensing engines. Both types are in common use, but the condensing engines are much more economical than the noncondensing, as far as fuel is concerned; but to condense the steam, considerable water is necessary, and condensing engines cost more and require more care. Consequently in some cases it is quite as economical, all things considered, to use the noncondensing engine.

COOLING TOWERS.

It sometimes happens that it is impossible to place a steam plant in close proximity to a natural water supply. In such cases the water necessary for the condenser (the circulating water) is expensive, and if the cost is very great it does not pay to add the condenser, because the cost of the circulating water might more than offset the gain from condensing. If, however, some means could be provided whereby the circulating water as it issues from the condenser could be cooled and then used over again in the condenser, the noncondensing engine could then be run condensing; thus taking advantage of all the benefits due to the use of reduced back pressure and heating of the feed water. This has been attempted by conducting the heated discharge water to a pond, where it is allowed to cool to a lower temperature before being used again. Another plan is to place in the yard or on the roof of the building large shallow pans, in which the water is cooled by being exposed to the atmosphere. These methods are unsatisfactory on account of the considerable area necessary and the slow action. In addition they are uncertain, because they are dependent upon atmospheric conditions.

A more efficient and at the same time more expensive process is to use a cooling tower or a water table. Fig. 31 shows the general arrangement of a cooling tower located upon the roof of a building. The discharge from the condenser is led, as shown by the arrows, to the top of the cooling tower, where it is cooled before being returned to the condenser. This cooling is effected by distributing the water, by a system of piping, to the upper edge of a series of mats or slats, over the surface of which the water

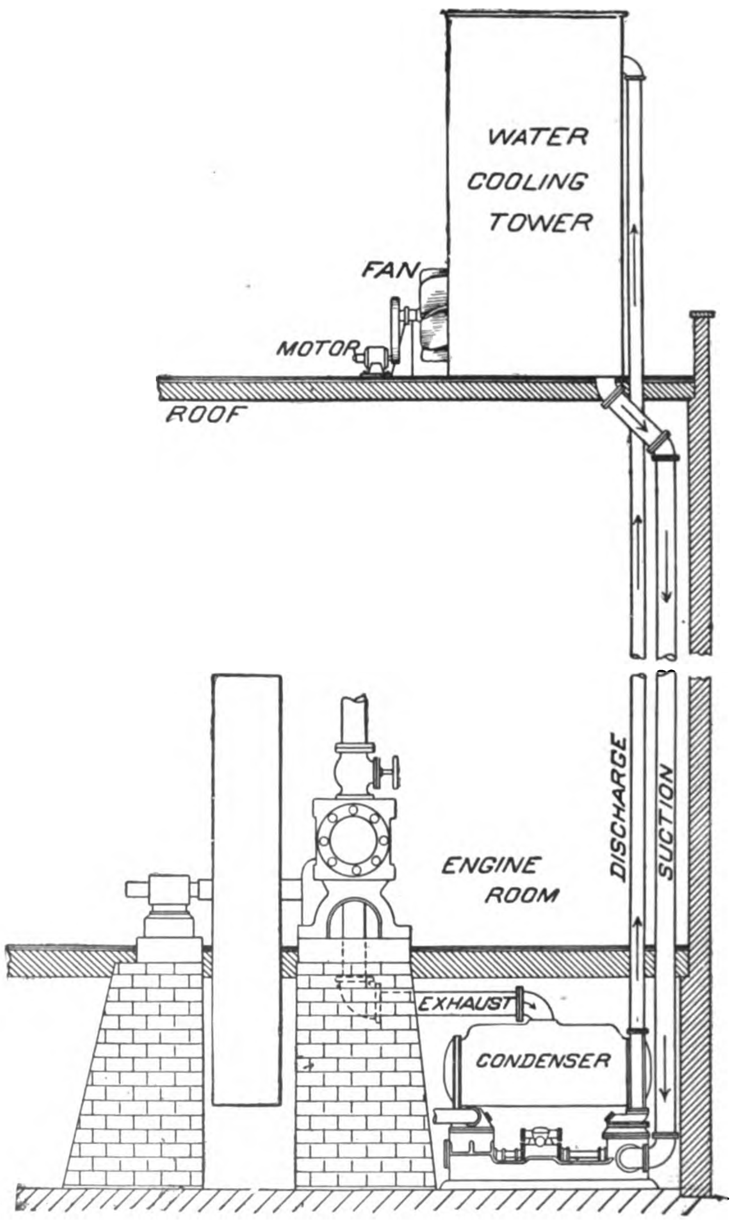

WATER
COOLING
TOWER
FAN
MOTOR
ROOF
DISCHARGE
SUCTION
ENGINE
ROOM
EXHAUST
CONDENSER

Fig. 81.

flows in a thin film to a reservoir which is situated in the bottom of the cooling tower. The mats partially interrupt the flow, and by breaking up the water in small streams cause new portions to be exposed to the cooling effect of the air currents. The water from the reservoir then flows downward through the suction pipe, and is pumped by the circulating pump through the condenser. After passing through the condenser and absorbing heat from the exhaust steam, it rises through the discharge pipe and commences the circuit over again.

The tower may have several arrangements and be made of various materials. A satisfactory form is constructed of steel plates; within the tower are a large number of mats of steel wire cloth galvanized after weaving.

To assist in the cooling of the water, the air is often made to circulate rapidly by means of a fan, which forces the air into the lower part of the tower and upwards among the mats. This fan is usually of the ordinary type, and may be driven by an electric motor, a line of shafting, or by a small independent engine.

In case the fan is not used, the mats are arranged so that they are exposed to the atmosphere, as shown in Fig. 32. This of course necessitates the removal of the steel casing. Usually the fanless tower must be placed at the top of a high building, or in some position where the currents of air can readily circulate among the mats.

With an efficient type of cooling tower the water may be reduced from 30 to 50°, thus allowing a vacuum of from 22 to 26 inches. This will of course greatly increase the economy of the plant, and allow the heated feed water to be returned to the boiler

The water table is usually made of wooden slats placed in the ground near the plant. After trickling over the slats and becoming cooled by the air, it collects in the bottom of the reservoir and is then pumped into the condenser.

THE FLY WHEEL.

It is evident that while the piston can push the crank around during part of the stroke, and pull it during another part, there are still two places (called dead points) at the ends of the stroke, where the pressure on the piston, no matter how great, can exert

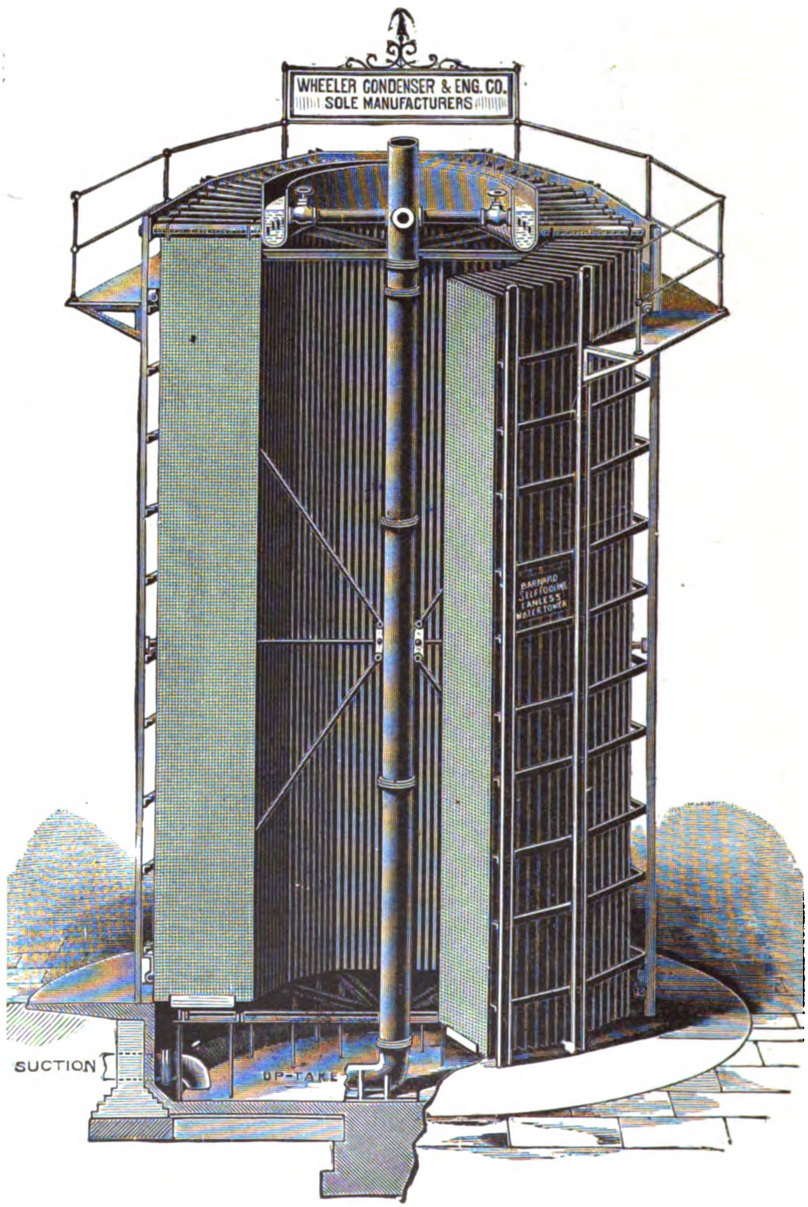

WHEELER CONDENSER & ENG. CO.
SOLE MANUFACTURERS
BARNARD
SELF COOLING
FANLESS
SUCTION
UP-TAKE

Fig. 32.

no turning moment on the shaft. Therefore, if some means is not provided for making the shaft turn past these points without the assistance of the piston, it may stop. This means is provided in the fly wheel, which is merely a heavy wheel placed on the shaft. On account of the momentum of the fly wheel it cannot be stopped quickly, and therefore carries the shaft around until the piston can again either push or pull.

If a long period be considered, the mean effort and the mean resistance must be equal; but during this period there are temporary changes of effort, the excesses causing increase of speed. To moderate these fluctuations several methods are employed.

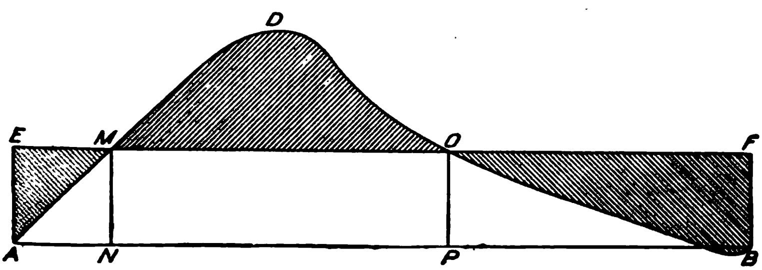


Fig. 33.

The turning moment on the shaft of a single cylinder engine varies, first, because of the change in steam pressure, and second, on account of the angularity of the connecting rod. Before the piston reaches mid-stroke the turning moment is a maximum, as shown by the curve, (Fig. 33). While near the ends of the stroke (the dead points) the turning moment diminishes and finally becomes zero. This, of course, tends to cause a corresponding change in the speed of rotation of the shaft. In order to have this speed as nearly constant as possible, and to give a greater uniformity of driving power, the engine may be run at high speed. By this means the inertia of the revolving parts, such as the connecting rod and crank, causes less variation. When the work to be done is steady and always in the same direction (as in most factories), a heavy fly wheel may be used.

The heavier the fly wheel, the steadier will be the motion. It is, of course, desirable in all factory engines to have steady motion, but in some it is more important than in others. For

instance, in a cotton mill it is absolutely necessary that the machinery shall move with almost perfect steadiness; consequently mill engines always have very large, heavy fly wheels. It is undesirable to use larger wheels than are absolutely necessary, because of the cost of the metal, the weight on the bearings and the danger from bursting.

If the turning moment which is exerted on the shaft from the piston could be made more regular, and if dead points could be avoided, it would be possible to get a steadier motion with a much smaller fly wheel.

If the engine must be stopped and reversed frequently, it is better to use two or more cylinders connected to the same shaft. The cranks are placed at such angles that when one is exerting its minimum rotative effort, the other is exerting its maximum turning moment; or, when one is at a dead center, the other is exerting its greatest power. These two cylinders may be identically the same, as is the case with most hoisting engines and with many locomotives; or the engine may be compound or triple expansion.

This arrangement is also used on engines, for mines, collieries, and for hoisting of any sort where ease of stopping, starting and reversing are necessary. Simple expansion engines with their cranks at right angles are said to be coupled.

The governor adjusts the power of the engine to any large variation of the resistance. The fly wheel has a duty to perform which is similar to that of the governor. It is designed to adjust the effort of the engine to sudden changes of the load which may occur during a single stroke. It also equalizes the variation in rotative effort on the crank pin. The fly wheel absorbs energy while the turning moment is in excess of the resistance and restores it while the crank is at or near the dead points. During these periods the resistance is in excess of the power.

The action of the fly wheel may be represented as in Figs. 33 and 34. It will be noticed that in Fig. 33 the curve of crank effort runs below the axis toward the end of the stroke. This is because the compression is greater than the pressure near the end of expansion, and produces a resultant pressure on the piston. In Fig. 34 the effect of compression has been neglected. Let us suppose that the resistance, or load, is uniform. In Fig. 33 the line

A B is the length of the semi-circumference of the crank pin, or it is the distance the crank pin moves during one stroke. The curve A M D O B is the curve of turning moment for one stroke. M N is the mean ordinate, and therefore A E F B represents the constant resistance. The effort and resistance must be equal if the speed is uniform; hence A E F B = A M D O B. Then area A E M + area O F B = area M D O. At A the rotative effort is zero because the crank pin is at the dead point; from A to N the turning moment is less than the resistance. At N the resistance and the effort are equal. From N to P the effort is in excess of the resistance. At P the effort and resistance are again equal. From P to B the resistance is greater than the effort. In other words, from A to N the work done by the steam is less than the resistance.

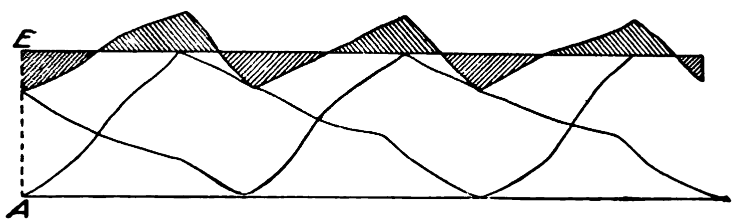


Fig. 34.

ance. This shows that the work represented by the area A E M must have been done by the moving parts of the engine. From N to P the work done by the steam is greater than the resistance, and the excess of energy is absorbed by or stored in the moving parts. From P to the end of the stroke, the work represented by the area O F B is done on the crank pin by the moving parts.

We know from the formula, $E = \frac{W V^2}{2g}$, that energy is proportional to the square of the velocity. Hence as W and g remain the same, the velocity must be reduced when the moving parts are giving out energy, and increased when receiving energy. Thus we see that the tendency of the crank pin is to move slowly, then more rapidly. The revolving parts of an engine have not sufficient weight to store this surplus energy, hence a heavy fly wheel is used.

In case there are two engines at right angles, two effort curves

must be drawn, as shown in Fig. 34. The mean ordinate A E is equal to the mean or constant resistance. There are two minimum and two maximum velocities in one stroke. The diagram shows that the variation is much less than for a single cylinder; hence a lighter fly wheel may be used.

The *weight of the fly wheel* depends upon the character of the work done by the engine. For pumping engines and ordinary machine work the effort need not be as constant as for electric lighting and fine work. In determining the weight of a fly wheel the diameter of the wheel must be known, or the ratio of the diameter of the wheel to the length of stroke. If the wheel is too large, the high linear velocity of the rim will cause too great a centrifugal force and the wheel is likely to break. In practice, about 6,000 feet per minute is taken as the maximum linear velocity of cast-iron wheels. When made of wood and carefully put together, the velocity may be taken as 7,000 to 7,500 feet per minute.

We know that linear velocity is expressed in feet per minute by the formula, $V = 2\pi R N$, or $V = \pi D N$.

Then if a wheel runs at 100 revolutions per minute, the allowable diameter would be,

$$6{,}000 = 3.1416 \times D \times 100$$
$$D = \frac{6{,}000}{3.1416 \times 100} = 19.1 \text{ feet.}$$

If a wheel is 12 feet in diameter the allowable speed is found to be,

$$N = \frac{V}{\pi D}$$
$$= \frac{6{,}000}{3.1416 \times 12} = 159 \text{ revolutions per minute.}$$

It is usual to make the diameter a little less than the calculated diameter.

Having determined the diameter, the weight may be calculated by several methods. There are many formulas to obtain this result given by various authorities. One formula is given as follows:

$$W = \frac{C \times d^2 \times b}{D^2 \times N^2}$$

In the above. $W =$ weight of the rim in pounds
$d =$ diameter of the cylinder in inches
$b =$ length of stroke in inches
$D =$ diameter of fly wheel in feet
$N =$ number of revolutions per minute

C is a constant which varies for different types and conditions.

Slide-valve engines, ordinary work,	C = 350,000
Corliss engines, ordinary work,	C = 700,000
Slide-valve engines, electric lighting,	C = 700,000
Corliss engines, electric lighting,	C = 1,000,000
Automatic high-speed engines,	C = 1,000,000

Example. Let us find the weight of a fly-wheel rim for an automatic high-speed engine used for electric lighting. The cylinder is 24 inches in diameter; the stroke is 2 feet. It runs at 300 revolutions per minute, and the fly wheel is to be 6 feet in diameter.

$$W = 1,000,000 \times \frac{(24)^2 \times 24}{36 \times 90,000}$$

$$W = 4,266 \text{ pounds}$$

Another example. A plain slide-valve engine for electric lighting is $20'' \times 24''$. It runs at 150 revolutions per minute. The fly wheel is to be 8 feet in diameter. What is the weight of its rim?

$$W = 700,000 \times \frac{400 \times 24}{64 \times 22,500}$$

$$W = 4,666 \text{ pounds.}$$

The weight of a fly wheel is considered as being in the rim. The weight of the hub and arms is simply extra weight. Then, if we know the weight of the rim and its diameter, we can find the width of face and thickness of rim. Let us assume the given diameter to be the mean of the diameter of the inside and outside of the rim.

Let $b =$ width of face in inches
$t =$ thickness of rim in inches
$d =$ diameter of fly wheel in inches
$.2607 =$ weight of 1 cubic inch of cast iron

Then,

$$W = .2607 \times b \times t \times \pi d$$
$$= b \times t \times .819\, d$$

Suppose the rim of a fly wheel weighs 6,000 pounds, is 9 feet in diameter, and the width of the face is 24 inches. What is the thickness of the rim?

$$t = \frac{W}{.819\,d\,b}$$

$$= \frac{6{,}000}{.819 \times 108 \times 24}$$

$$= 2.83 \text{ inches}$$

In this case the rim would probably be made $2\frac{13}{16}$ inches thick. The total weight, including hub and arms, would probably be about 8,000 pounds.

GOVERNORS.

The load on an engine is never constant, although there are cases where it is nearly uniform. While the engine is running at constant speed, the resistance at the fly-wheel rim is equal to the work done by the steam. If the load on the engine is wholly or partially removed, and the supply of steam continues undiminished, the force exerted by the steam will be in excess of the resistance. Work is equal to force multiplied by distance; hence, with constant effort, if the resistance is diminished, the distance must be increased. In other words, the speed of the engine will be increased. The engine will "race," as it is called. Also, if the load increases and the steam supply remains constant, the engine will "slow down."

It is evident, then, that if the speed is to be kept constant some means must be provided so that the steam supply shall at all times be exactly proportional to the load. This is accomplished by means of a governor.

Steam-engine governors act in one of two ways: they may regulate the *pressure* of steam admitted to the steam chest, or they may adjust the speed by altering the *amount* of steam admitted. Those which act in the first way are called throttling governors, because they throttle the steam in the main steam pipe. Those of the latter class are called automatic cut-off governors, since they automatically regulate the *cut-off.*

Theoretically, the method of governing by throttling the

steam causes a loss in efficiency, but the throttling superheats the steam, thus reducing cylinder condensation. By the second method the loss in efficiency is very slight, unless the ratio of expansion is already great, in which case shortening the cut-off causes more cylinder condensation. This subject will be taken up in detail later.

In most governors, centrifugal force, counteracted by some other force, is employed. A pair of heavy masses (usually iron balls or weights) are made to revolve about a spindle, which is driven by the engine. When the speed increases, centrifugal force increases, and the balls tend to fly outward; that is, they revolve in a larger circle. The controlling force, which is usually gravity or springs, is no longer able to keep the balls in their former path. When, therefore, the increase is sufficiently great, the balls in moving outward act on the regulator, which may throttle the steam or cause cut-off to occur earlier.

With the throttling governor a balanced throttle valve is placed in the main steam pipe leading to the valve chest. If the engine runs faster than the desired speed, the balls are forced to revolve at a higher speed. The increase in centrifugal force will cause them to revolve in a larger circle and in a *higher plane.* By means of some mechanism (levers and gears) the spindle may be forced downward, thus partially closing the valve. The engine, therefore, takes steam at a lower pressure, and the power supplied being less, the speed falls slightly.

Similarly, if the load is increased, the engine slows down, which causes the balls to drop and open the valve more widely, steam at higher pressure is then admitted, and the speed is increased to the regular number of revolutions.

With the Corliss or Wheelock engine the governor of this type acts differently. Instead of throttling the steam in the steam pipe, the governor is connected to the releasing gear by rods. An increase of speed causes the releasing gear to unhook the disengaging link earlier in the stroke. This causes earlier cut-off, which of course decreases the power and the speed, since the amount of steam admitted is less. If for any reason the load increases, the governor causes the valves to be held open longer. The cut-off, therefore, occurs later in the stroke.

One of the most common forms of governor is similar to that invented by James Watt. It is called, from its appearance, the pendulum governor. It is shown in Fig. 35. To consider the theory of the pendulum governor, the masses of the balls are assumed to be concentrated at their centers, and the rods made of some material having no weight.

When the governor is revolving about its axis at a constant speed the balls revolve in a circle having a radius r The distance from this plane to the intersection of the rods, or the rods produced, is called the height and is equal to h.

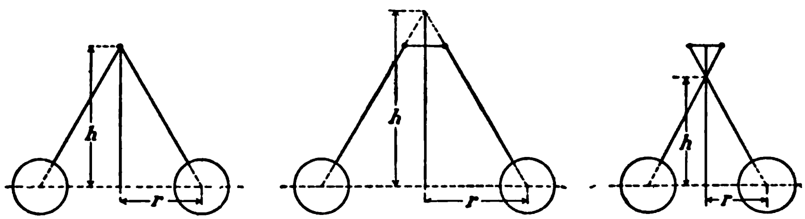


Fig. 35.

If the balls revolve faster, the centrifugal force increases, r becomes greater and h diminishes. We know that centrifugal force is expressed by the formula,

$$F = \frac{Wv^2}{g\,r}$$

Then centrifugal force varies inversely as the radius.

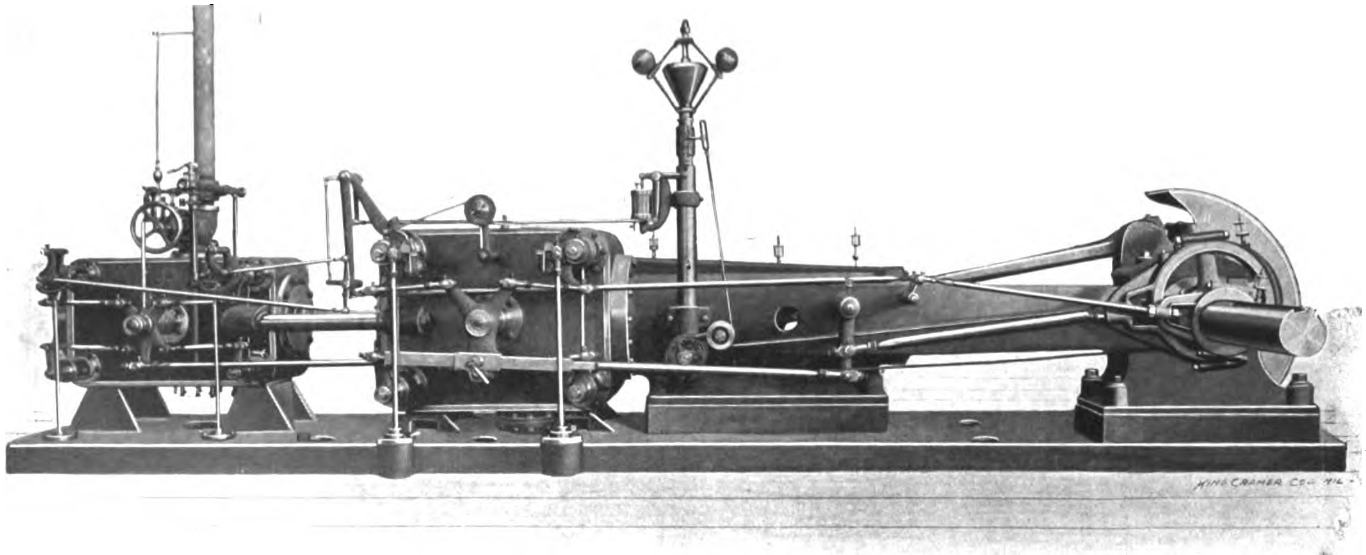
While the pendulum is revolving, centrifugal force acts horizontally outward and tends to make the balls fly from the center; gravity tends to make the balls drop downward. In order that the balls shall revolve at a certain height, the moments of these two forces about the center must be equal, or the weight of the balls multiplied by their distance from the center must equal the centrifugal force multiplied by the height, or.

$$W \times r = F \times h$$

from which,
$$\frac{h}{r} = \frac{W}{F}$$

or,
$$\frac{h}{r} = \frac{W}{\frac{Wv^2}{g\,r}} = \frac{g\,r}{v^2}$$

from which,
$$h = \frac{g\,r^2}{v^2}$$



TANDEM CORLISS ENGINE DRIVING ELECTRIC LIGHT PLANT. TRADESMEN'S NATIONAL BANK, PITTSBURG.
Nordberg Manufacturing Company.

Now we know that the linear velocity of a point revolving in the circumference of a circle is expressed as $2\,\pi\,r\,N$ feet per second.

Then, $$h = \frac{g\,r^2}{v^2} = \frac{g\,r^2}{4\pi^2\,r^2\,N^2} = \frac{g}{4\pi^2\,N^2}$$

Since we know the values of g and π we can write the formula,

$$h = \frac{32.16}{4 \times 3.1416^2 \times N^2} = \frac{.8146}{N^2} \text{ feet per second, or}$$

$$h = \frac{9.775}{N^2} \text{ inches per second.}$$

If N is the number of revolutions per minute, since $60^2 =$ 3600,

$$h = \frac{2{,}932.56}{N^2} \text{ feet}$$

$$h = \frac{35{,}190.7}{N^2} \text{ inches}$$

From the above formula, we see that the height is independent of the weight of the balls or the length of the rod; it depends upon the number of revolutions. The height varies inversely as the square of the number of revolutions.

The ordinary pendulum governor is not isochronous; that is, it does not revolve at a uniform speed in all positions; the speed changes as the angle between the arms and the spindle changes.

The early form consisted of two heavy balls suspended by links from a pin connection in a vertical spindle, as shown in Figs. 36 and 37. The spindle is caused to revolve by belting or gearing from the main shaft, so that as the speed increases, centrifugal force causes the balls to revolve in a circle of larger and larger diameter. The change of position of these balls can be made to affect the controlling valves so that the admission or the throttling shall vary with their position. With this governor it is evident that for a given speed of the engine there is but one position possible for the governor; consequently one amount of throttling or one point of cut-off, as the case may be. If the load varies, the speed of the engine will change. This causes the position of the governor balls to be changed slightly, thus altering the pressure

But in order that the pressure or cut-off shall remain changed, the governor balls must stay in their new position. That is to say, the speed of the engine must be slightly changed. Thus with the old ball governors there was a slightly different speed for each load. This condition has been greatly improved by various modifications until now such governors give excellent regulation.

While the engine is running with a light load, the valve controlled by the governor will be open just enough to admit steam at a pressure that will keep the engine running at a given speed. Now, if the engine is heavily loaded, the throttle valve must be wide open. The change of opening is obtained by a variation in the height of the governor, which is caused by a change of speed. Thus we see that the governor can control the speed only within certain limits which are not far apart. The difference in the extreme heights of the governor must be sufficient to open the throttle its entire range. In most well-designed engines the speed will not vary more than 4 per cent; that is, 2 per cent above or below the mean speed.

From the formula $h = \frac{35,190.7}{N^2}$, we can compute the heights corresponding to given speeds as shown by the following table:

Number of Revolutions per Minute.	Height in Inches.	Variation of Height in Inches 4 per cent.
250	.563	.0225
200	.879	.035
175	1.149	.046
150	1.564	.062
125	2.252	.090
100	3.519	.140
75	6.256	.250
50	14.076	.563

In the above table the second column is found from the formula $h = \frac{35,190.7}{N^2}$. The third column is the variation in height for a speed variation of 4 per cent or 2 per cent either above or below the mean.

From the table we see that for a considerable variation of speed there is but slight variation in the height of the governor. Also for high speeds the height of the governor is so small that it would be difficult to construct it. The slight variation in height is too small to control the cut-off or throttling mechanism throughout the entire range.

Other disadvantages of the fly-ball governor are as follows: it is apparent that the valves must be controlled by the weight of the governor balls. In large engines this requires very heavy balls in order to quickly overcome the resistance of the valves. But these large balls have considerable inertia and will therefore be reluctant to change their speed with that of the engine. The

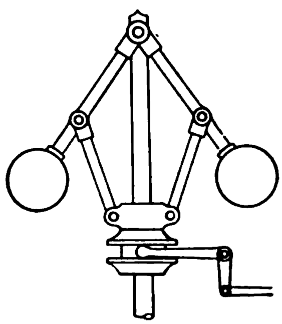


Fig. 36.

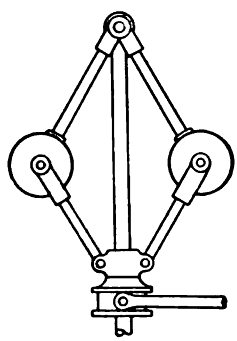


Fig. 37.

increased weight will also increase the friction in the governor joints, and the cramping action existing when the balls are driven by the spindle will increase this friction still further. All these things tend to delay the action of the governor, so that in all large engines the old-fashioned governor became sluggish. The balls had to turn slowly because they were so heavy; this was especially troublesome in high-speed engines.

To remedy these defects the weighted or Porter governor was designed. (See Fig. 38.) It has a greater height for a given speed, and the variation in height for a given variation of speed is greater. When a governor has this latter quality, that is, a great variation in height for a given variation of speed, it is said to be sensitive. By increasing this variation in height the sensitiveness is increased. Thus, if a governor running at 50 revolutions has a

variation in height of .57 inch, it is not as sensitive as one having a variation of 1 inch for the same speed.

In the weighted governor, the weight is formed so that the center of gravity is in the axis. It is placed on the spindle and is free to revolve. The weight adds to the weight of the balls, and thus increases the moment of the weight. It does not, however, add to the centrifugal force, and hence the moment of this force is unchanged. We may then say the weight adds effect to the weight but not to the centrifugal force, and as a consequence the height of the governor, for a given speed, is increased. If we let W equal the combined weight of the balls as before, and W′ equal the added weight, the moments are,

$$(W + W') \times r = F\,h$$

$$(W + W') \times r = \frac{W\,v^2}{g\,r} \times h$$

$$h = (W + W')\,r \times \frac{g\,r}{W\,v^2}$$

$$= \frac{(W + W')\,r^2\,g}{W \times 4\,\pi^2\,r^2\,N^2}$$

$$= \frac{(W \times W')}{W} \times \frac{g}{4\,\pi^2\,N^2}$$

We know that $\frac{g}{4\,\pi^2\,N^2} = \frac{.8146}{N^2}$.

Then $h = \left\{ \frac{W + W'}{W} \right\} \times \frac{.8146}{N^2}$.

Hence the height of a weighted governor is equal to the height of a simple pendulum governor multiplied by

$$\left\{ \frac{W + W'}{W} \right\} \text{ or } \left\{ 1 + \frac{W'}{W} \right\}.$$

For instance, if the height of a simple pendulum is 10 inches, and the weight of the balls equal to the added weight, the height will be,

$$h = \left\{ \frac{1 + 1}{1} \right\} \times 10$$

$$= 2 \times 10$$

Thus we see that if a weight equal to the combined weight of the balls is added, the height of the governor will be doubled.

We know that if the balls fall, the cut-off comes later. If the belt driving the governor slips off or breaks, the balls will drop, and, making the cut-off later, will allow the engine to "run away." To diminish this danger many governors are provided with some kind of safety stop, which closes the valve when the governor loses its normal action. Usually a trip is provided which the governor does not touch in its normal positions, but which will be released if the balls drop down below a certain point.

In another arrangement, instead of a weight, a strong spring is used, and this makes it possible to put the governor in any position.

Spring Governors. In many cases a spring is used in place of the weight. This type of governor is used frequently on throttling engines; it consists of a pendulum governor with springs added to counteract the centrifugal force of the balls. Thus the height and sensitiveness are increased. Fig. 39 shows the exterior view of a Waters governor, and Fig. 40 the same governor having the safety stop. In this governor the weights are always in the same plane, the variation in height being due to the action of the bell crank levers connecting the balls and spindle. When the balls move outward the spindle moves downward and tends to close the valve. The governor balls revolve by means of a belt and bevel gears. The valve and seat are shown in section in Fig. 41. The valve is a hollow cylinder with three ports, by means of which steam enters the valve. The seat is made in four parts, that is, there are four edges that the steam passes as it enters the valve. The valve being cylindrical and having steam on both sides is balanced, and because of the many openings only a small travel is necessary.

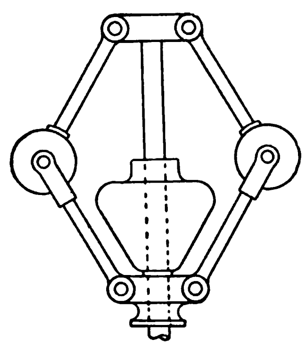


Fig. 38.

Shaft Governors. Usually some form of pendulum governor

is used for throttling engines. For governing an engine by varying the point of cut-off, shaft governors are generally used; however, Corliss engines and some others use pendulum governors for this purpose. Cut-off governors are called shaft governors because they are placed on the main shaft; they are made in many forms, but the essential features of all are the same. Two pivoted masses or weights are arranged symmetrically on opposite sides of the shaft, and their tendency to fly outward when the speed increases is resisted by springs. The outward motion of the weights closes the admission valve earlier, and the inward motion closes it later. This change is effected by altering the position of the eccentric, either by changing the eccentricity or the angular advance.

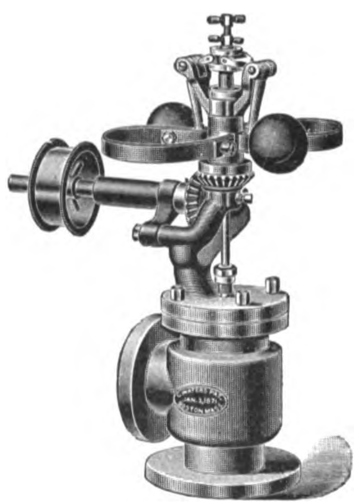


Fig. 39.

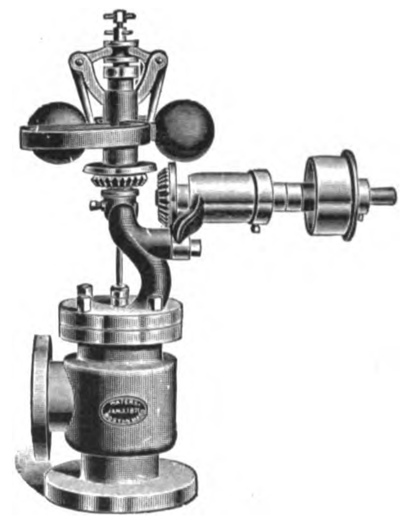


Fig. 40.

Shaft governors are made in a great variety of ways, no two types being exactly alike. If the principles of a few types are understood, it is easy to understand others. The following illustrates two common methods of shifting the eccentric.

Buckeye Engine Governor. The valve of the Buckeye engine is hollow and of the slide valve type. The cut-off valve is inside. The change of cut-off is due to the alteration of the angular advance. The arrangement of the parts which effect the change of angular advance is shown in Fig. 42. A wheel which

contains and supports the various parts of the governor is keyed to the shaft. Two arms, having weights A A at the ends, are pivoted to the arms of the wheel at *b b*. The ends having the weights are connected to the collar on the loose eccentric C by means of rods B B.

When the weights move to the position indicated by the dotted lines, the eccentric is turned on the shaft about a quarter of a revolution in the direction in which the engine runs. That is, the eccentric is advanced or the angular advance is increased. Now we know that if the angular advance is increased, cut-off occurs earlier. This is shown by the table on page 12 of "Valve Gears." If the engine had a single plain slide valve the variation of the angular advance would produce too great a variation of lead; but as this engine has a separate valve for cut-off, admission is not altered by the cut-off valve.

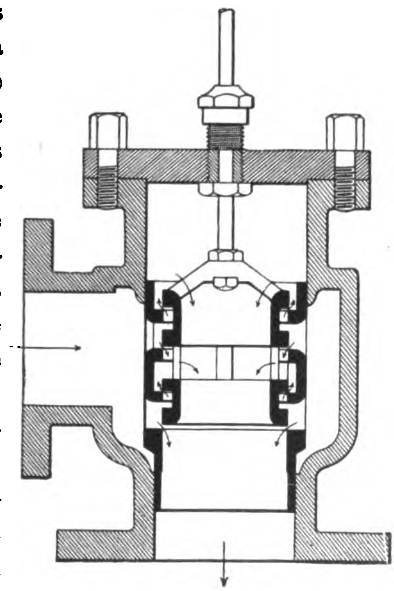


Fig. 41.

The springs F F balance the centrifugal force of the weights. The weights A A are varied to suit the speed; the tension on the springs is altered by means of the screws *c c*. Auxiliary springs are added in order to obtain the exactness of regulation necessary for electric lighting. These springs tend to throw the arms outward, but act only during the inner half of this movement.

The Straight-Line Engine Governor. Fig. 43 shows the governor of the straight-line engine. It has but one ball, B, which is linked to the spring S and to the plate D E, on which is the eccentric C. When the ball flies outward in the direction indicated by the arrow F, the eccentric is shifted about the pivot O; the links moving in the direction of arrow H. The ball is heavy and at a considerable distance from the center; hence it has a great centrifugal force, and the spring must be stiff.

The governor of the Buckeye engine alters the cut-off by changing the *angular advance.* The straight-line engine governor changes the *travel* of the valve. Shaft governors which alter the cut-off by changing the valve travel are very common.

LUBRICATION.

If two pieces of cast iron, just as they come from the foundry, are rubbed together, they will not slide over each other easily, because of little projections. If this same iron is filed or planed,

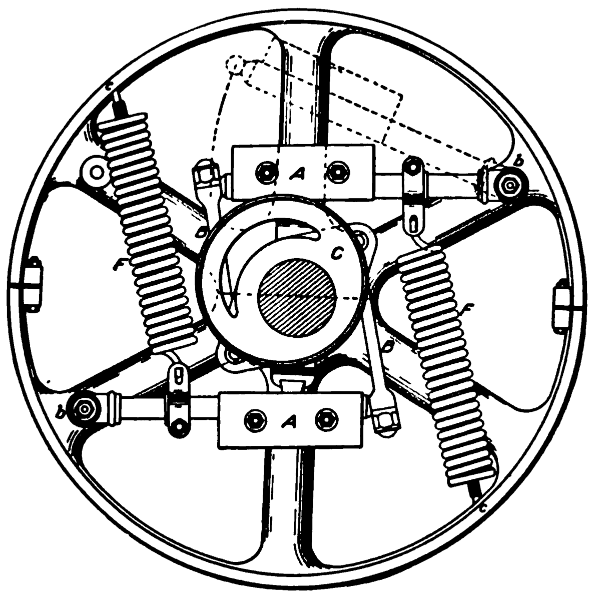


Fig. 42.

the pieces will slide much more easily. This is because the rough places have been smoothed, or filled up with dust. If now we put some engine oil on the pieces, they will slide very easily. This is because the more minute depressions have been filled up and the whole surface is made comparatively smooth. No matter how carefully we might plane and polish any surface, a microscope would show that it was still a little rough.

One cause of loss of power in the steam engine is friction. In all engines there are so many moving parts that it is of great importance that friction should be reduced as much as possible. This is

done by making the surfaces in contact smooth and of ample size; also making them of different metals and using oils or other lubricants. The effect of the lubricant is to interpose a thin film between the surfaces. This prevents their coming into actual contact. If the oil is too thin or the pressure too great, the lubricant is squeezed out and the metal surfaces come in contact.

Thus we see that there are certain qualities which a lubricant must have. They are as follows:

The lubricant must be sufficiently fluid, so that it will not itself make the bearing run hard.

It must not be too fluid or it will be squeezed out from between the bearing surfaces. If this happens, the bearing will

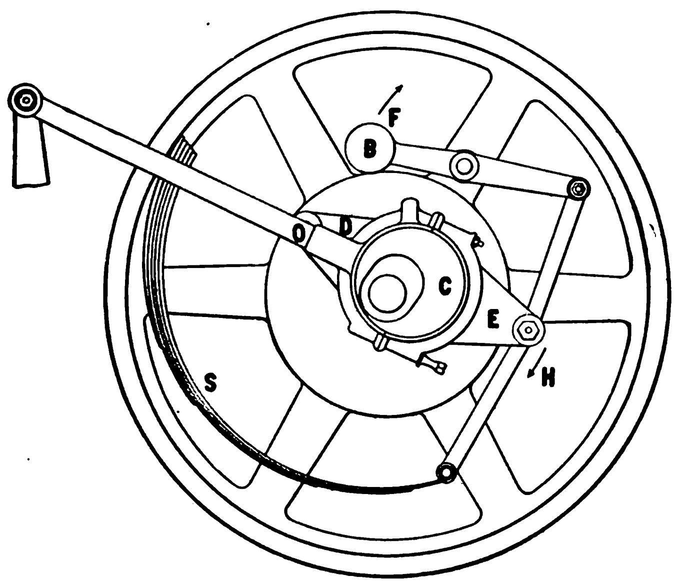


Fig. 43.

immediately begin to heat and cut. The heating will tighten the bearing, and will thus increase the pressure and the cutting.

It must not gum or dry when exposed to the air.

It must not be easily decomposed by the heat generated. If it should be decomposed, it might form substances which would be injurious to the bearings.

It must not take fire easily.

It must contain no acid, and should form no acid in decomposing, as acids corrode the bearings.

Both *mineral* and *animal* oils are used as lubricants. Formerly animal oils were used entirely, but they were likely to decompose at high temperatures and form acids. It is important in using high-pressure steam to have "high-test oils," that is, oils which will not decompose or volatilize at the temperature of the steam. It was the difficulty of getting such oils which made great trouble when superheated steam was first used. Mineral oils will stand these temperatures very readily, and even if they do decompose, they form no acids.

The Liquid Lubricants, whether of animal, vegetable or mineral origin, may be used for ordinary bearings, but for valves and pistons heavy mineral oils only are suitable.

Solid Lubricants. *Graphite* is used as a lubricant. It is well adapted for heavy pressures when mixed with certain oils. It is especially valuable for heavy pressures and low velocities.

Metalline is a solid compound, containing graphite. It is made in the form of solid cylinders, which are fitted to holes drilled into the surface of the bearing. When a bearing is thus fitted no other lubricant is necessary.

Soapstone in the form of powder and mixed with oil or fat is sometimes used as a lubricant. Soap mixed with graphite or soapstone is often used where wood is in contact with wood or iron.

A preparation called *Fiber Graphite* is used for self-lubricating bearings. It is made of finely divided graphite mixed with fibers of wood. It is pressed in molds and afterward fitted to bearings.

For great pressure at slow speed, graphite, lard, tallow and other solid lubricants are suitable. If the pressure is great and the speed high, castor, sperm and heavy mineral oils are used.

For low pressure and high speed, olive, sperm, rape and refined petroleum give satisfaction.

In ordinary machinery, heavy mineral and vegetable oils and lard oil are good. The relative value of various lubricants depends upon the prevailing conditions. Oil that is suitable for one place might not flow freely enough for another.

The quality of oil is of great importance. In many branches

of industry it is imperative that the machinery run as perfectly as possible. On this account and because of the high cost of machinery, only first-class oil should be used. The cylinder oil especially, should be high grade, because the valves, piston and piston rods are the most delicate parts of the engine.

Engines are lubricated by means of oil cups and wipers placed on the bearings wherever required. They are made in many forms, dependent upon the manufacturers. Commonly the oil cup is made with a tube extending up through the oil. A piece of lampwick or worsted leads from the oil in the cup to the tube. Capillary attraction causes the oil to flow continuously and drip down the tube. When not in use, the lampwick should be withdrawn.

The needle oil cup differs from the capillary oil cup in that a small wire or needle extends through the tube and oil; one end rests on the journal to be lubricated. The needle should fit the tube closely, so that when the machinery is at rest no oil will flow. When revolving, the shaft gives the needle a wabbling motion which makes the oil flow. To increase the supply, a smaller needle is used.

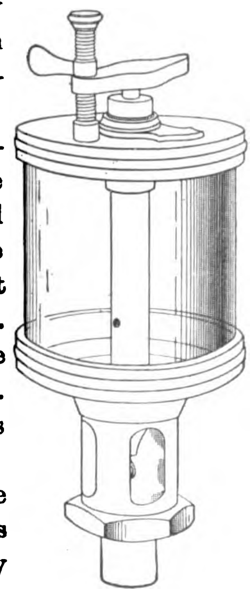


Fig. 44.

The oil cup shown in Fig. 44 is simple and economical. The opening of the valve is regulated by an adjustable stop. The oil may be seen as it flows drop by drop. The cylindrical portion is made of glass, so that the engineer can see how much oil there is in the cup without opening it.

A form of wiper crank pin oiler is shown in Fig. 45. The oil cup is attached to a bracket. The oil drops from the cup into a sheet of wicking or wire cloth and is removed at each revolution of the crank pin by means of the cup which is attached to the end of the connecting rod.

Fig. 46 shows a centrifugal oiling device. The oil flows from the oil cup through the tube to the small hole in the crank

pin by centrifugal force. It reaches the bearing surface by means of another small hole.

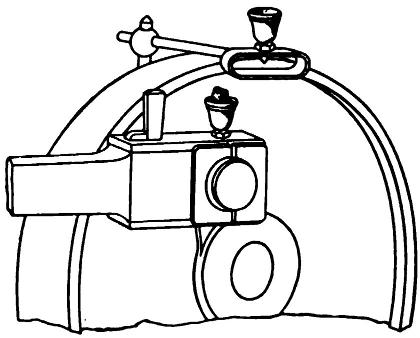


Fig. 45.

In oiling the valve chest and cylinder the lubricant must be introduced against the pressure of the steam. This can be done in several ways, in each of which it is introduced into the steam before it reaches the valve chest and is carried to the surfaces to be lubricated.

The oil can be forced into the steam pipe by a small hand pump or in large engines by an attachment from the engine itself. The supply of oil is, of course, intermittent if the pump is driven by hand, but continuous and economical if driven by the engine.

Sight Feed Lubricators. The most common device for feeding oil to the cylinder is that which introduces the oil drop by drop into the steam when it is in the steam pipe or steam chest. The oil becomes vaporized and lubricates all the internal surfaces of the engine.

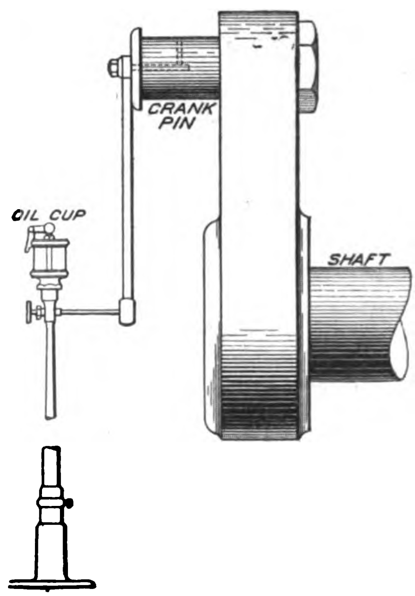


Fig. 46.

Fig. 47 shows the section of a sight feed lubricator. The reservoir O is filled with oil. The pipe B, which connects with the steam pipe, is partly filled with condensed steam, which flows down the small curved pipe E to the bottom of the chamber O. A small portion of the oil is thus displaced and flows from the top of the reservoir O down the tube F, by the

regulating valve D, and up through the glass tube S, which is filled with water. It enters the main steam pipe through the connection A. The gage glass G indicates the height of water in the chamber O. To fill the lubricator, close the regulating valve D and the valve in pipe B; the oil chamber can then be drained and filled. If the glass S becomes clogged it may be cleaned by shutting valve D and opening the small valve H. This will allow steam to blow through the glass. After cleaning close valve H and allow glass S to become filled with water before opening the feed valve. The amount of oil fed to the cylinder can be regulated by opening D (Fig. 47) the proper amount. The exact quantity of oil necessary for the engine is not easily determined. For ordinary sizes it is between one drop in two minutes and two drops per minute.

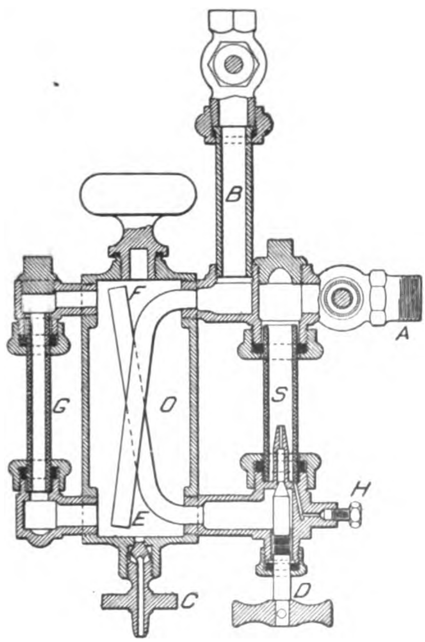


Fig. 47.

Graphite is an excellent lubricant and can be introduced into the cylinder dry or mixed with some heavy grease. It has been used extensively because of the trouble which cylinder oil gives in the exhaust and in the boilers of condensing engines.

In slow-speed engines it is not hard to attend to the oiling; all the parts are moving slowly and can be readily examined and oiled. Many high-speed engines run so fast that it is impossible to examine the various parts, and special means must be provided for lubricating. It is specially important in high-speed engines that there should be no heating. High-speed engines are generally used for electric lighting, and it is absolutely essential that they be kept running at the required speed to avoid flickering lights. Thus, while there is greater liability to heating in high-

speed engines, there is also much greater loss in case heating compels the stopping of an engine.

In order to avoid the danger of forgetting to oil a bearing of a high-speed engine, it is customary to have all the bearings oiled from one place. All the oil is supplied to one reservoir and from this reservoir pipes lead to all bearings. If this is not done, large oil cups are supplied, as a rule, so that oiling need not be attended to as frequently.

In some high-speed engines the moving parts are enclosed and the crank runs in a bath of oil. This secures certain oiling and is very effective. All the bearings may be inside this crank case, so that all are oiled in this way. It is impossible for a careless engineer to overlook one point and so endanger the whole engine.

STEAM TURBINE.

The very earliest records of the steam engine describe a form of steam turbine. It consisted of a hollow sphere, as shown in Fig. 48, mounted on trunnions, through which steam was admitted to the interior. This steam escaped through pipes bent tangentially to the equator line of the sphere. The force of the escaping steam reacted upon the sphere, causing it to revolve on its trunnions. Many centuries later, in 1629, Branca, an Italian, invented a rotary engine (Fig. 49), in which a jet of steam struck the vanes of a wheel, and thus forced it around in much the same way that a jet of water acts on a Pelton water-wheel. These engines were of little, if any, practical value, and used an immense quantity of steam.

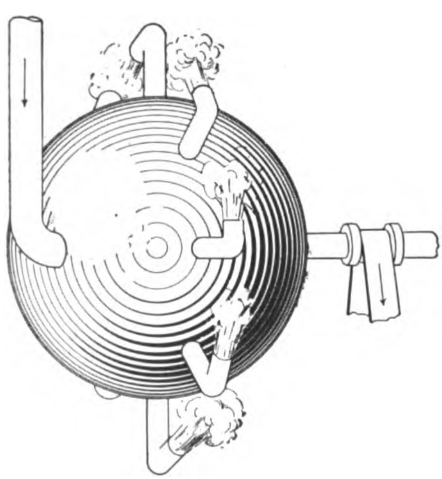


Fig. 48.

In 1705 the reciprocating engine was introduced, and by means of Watt's inventions became so efficient that the development of the rotary engine was out of the question. It will be remembered that Watt introduced the expansive use of steam in the reciprocating engine, which at this time could not be accomplished in the rotary engine, and until within the last few years practically nothing was done to develop the turbine.

Since the days of Watt there has been but one important thermodynamic improvement in the reciprocating engine; namely,

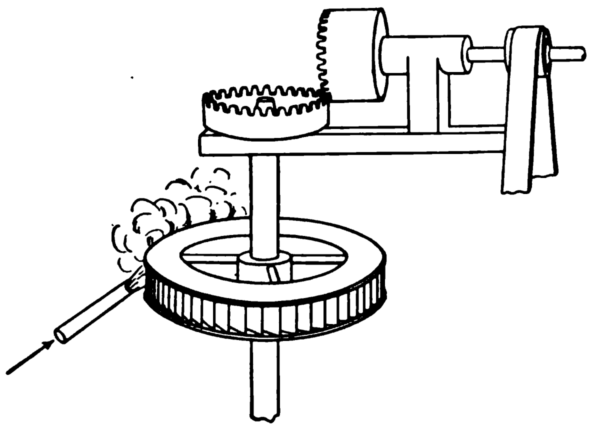


Fig. 49.

the introduction of compound expansion. All other improvements have been in the nature of mechanical devices, and it seems reasonable to suppose that the greatest developments of the future may possibly be in the production of some type other than the reciprocating engine.

In 1883 De Laval invented a successful turbine for running a cream separator, and a short time later Parsons introduced another. Both of these engines employed the expansive force of steam, but each derived this force in a different way.

Since 1883 the development of the turbine has been very rapid. The first engine introduced by De Leval, although far ahead of the earlier forms, was still very wasteful of steam; but now such improvements have been made that their steam consumption compares very favorably with the consumption of good reciprocating engines.

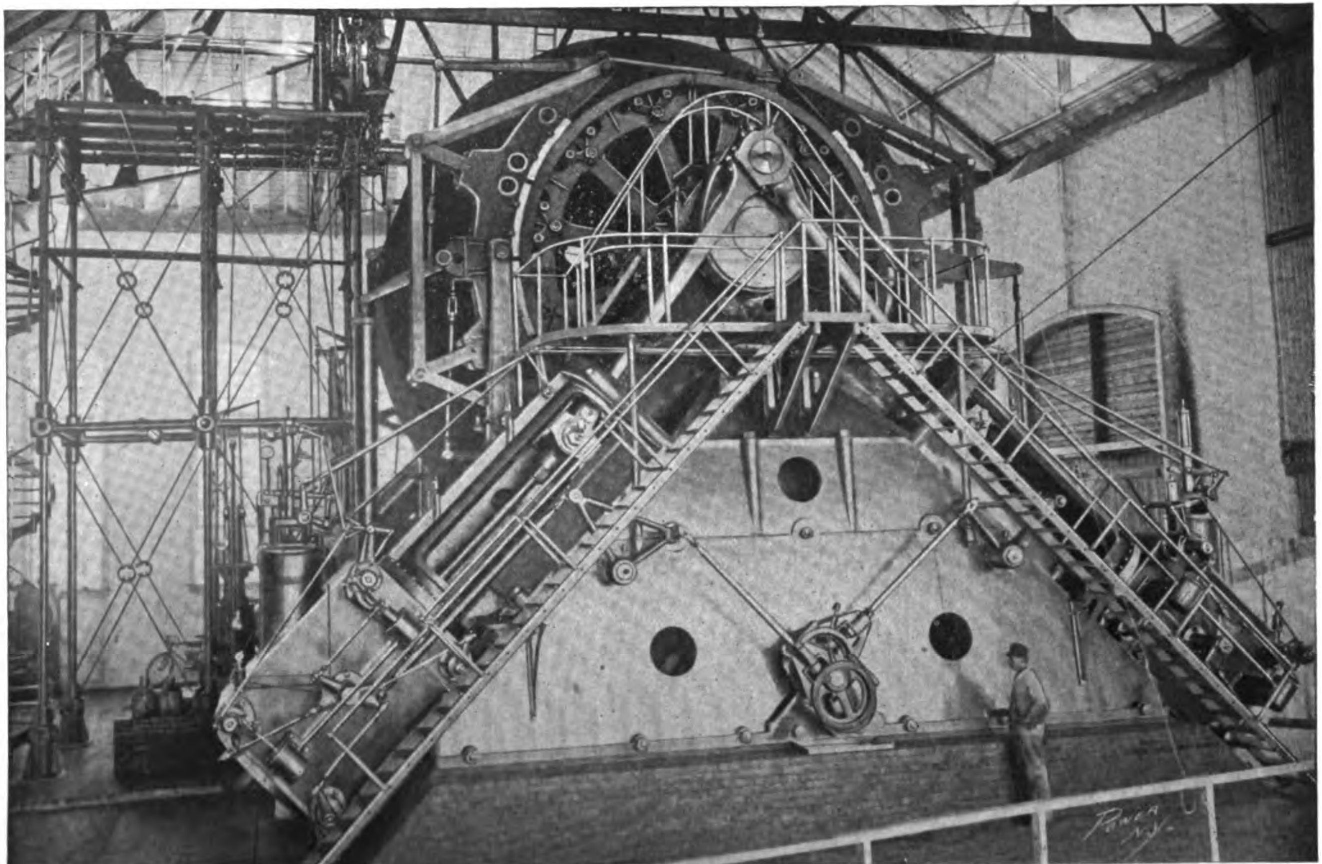
A modern turbine is a tremendously high-speed engine. It does not derive its power from the static force of steam expanding behind a piston, as in the reciprocating engine, but in this case the expanding steam produces kinetic energy of the steam particles. These particles receive a high velocity by virtue of the expansion, and, acting upon the vanes of a wheel, force it around at a high speed of rotation in some such manner as a stream of water rotates a water-wheel.

In the reciprocating engine the expansion produces a force which presses on the piston. In the rotary engine the expansion produces velocity in a jet of steam. This is the fundamental difference between the two forms.

The essential principles of water turbines are equally true of steam turbines. The jet must strike the vanes without a sudden shock, and must leave them in another direction without any sharp deflections. For maximum efficiency the De Laval engine should have a jet velocity equal to one-half the linear velocity of a point on the wheel-rim; for the Parsons these velocities should be equal. If the velocity of steam is 8,000 feet per second, it is easily seen that even one-half of this would cause too great a speed of rotation for safety. It would be difficult to build a wheel that would be strong enough to withstand the centrifugal force at this high speed. It becomes necessary, therefore, to reduce the speed to the limits of safety, and run under a slightly less efficiency.

At such high speed the shaft and wheel should be perfectly balanced, in order that its center of gravity may exactly coincide with the axis of rotation. In practice it has been found impossible to balance the shaft perfectly; and in order that it may revolve about its center of gravity, various means are adopted to overcome the rigidity of an ordinary shaft and bearing. This makes high speed of rotation possible without any apparent vibration.

De Laval Turbine. The De Laval turbine shown in Fig. 50 consists of a wheel with suitably shaped buckets, against which a jet of steam is directed. The buckets are on the rim of the wheel and are surrounded by a casing B, which prevents the escape of the steam until it has done its work. A piece of this casing is cut away at A in order to show the buckets. The steam



TAMARAK HOISTING ENGINE AT MINE.
Nordberg Manufacturing Co.

from the nozzle strikes these buckets and is deflected. Thus by the impact of the jet and the reaction due to its deflection, the wheel is caused to revolve at a high speed.

There are usually four nozzles that supply steam to the turbine, one of which is shown in section at D. These nozzles are small at the throat and diverge outward. By making them of the right length and with the proper amount of divergence, the steam can be expanded from the pressure of admission to the

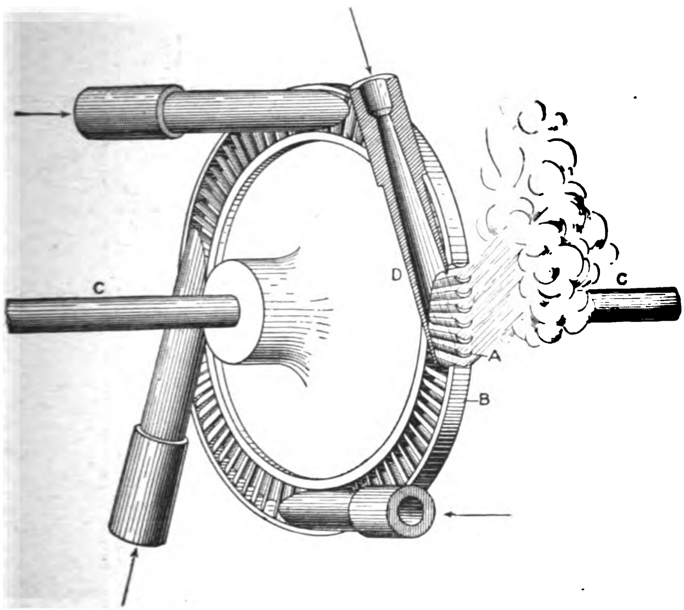


Fig. 50.

pressure of the condenser. Complete expansion is obtained in this diverging nozzle, and the steam leaves it at the exhaust pressure. The steam then works only by virtue of its high velocity.

This turbine has a long, flexible shaft C which can deflect enough to make up for any eccentricity of the center of gravity of the shaft, and thus allow the shaft to revolve about its center of gravity and still have rigid bearings at the end.

Admission is regulated by a throttle-valve, controlled by a fly ball governor.

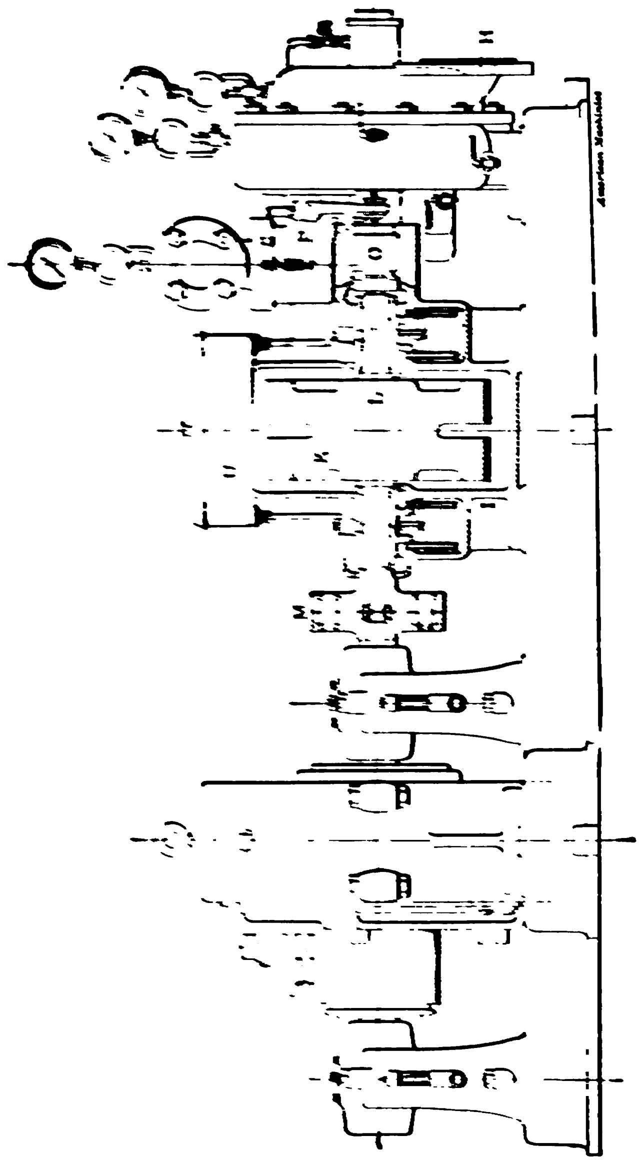


Fig. 51.

Fig. 51 shows a De Laval turbine connected with a generator.

The Parsons Turbine. Fig. 52 is a longitudinal section of a Westinghouse-Parsons turbine. Steam enters the chamber A and passes through the turbine vanes to the exhaust chamber B. The vanes are arranged as shown in Fig. 53, and consist of alternate sets, one stationary, the next movable. The steam strikes one and is deflected to the next; thus the action and the reaction occurring in rapid succession cause the movable sets, which are fixed to the shaft, to rotate at a high speed. As the steam passes the different sets of blades, the volume of the passages increases to correspond with the expansion of the steam. In the De Laval the steam was expanded entirely before reaching the wheel, but in the Parsons the expansion is accomplished in the engine itself. As the steam enters the chamber A (see Fig. 52) it presses on the turbine vanes and it also presses equally and in the opposite direction on C, which is really a piston fixed to the shaft. Thus we see that the pressure to the right is equal to the pressure to the left, and there is no end pressure on the bearing of the shaft. C_1 and C_2 balance the steam pressure in the chambers E and G. At H is a bearing which serves to maintain a correct adjustment of the balance pistons C. There is probably some escape of steam past these balancing pistons, but it is small. The exhaust steam at B presses the turbine toward the left, and would cause an end pressure on the bearing were it not that the pipe K opens a communication between the exhaust chamber B and the back of the balancing pistons, which makes the pressure equal at both ends.

The bearing consists of a gun-metal sleeve surrounded by three concentric tubes. There is a small clearance between these tubes which fills with oil and permits the bearing to run slightly eccentric to counteract any lack of balance in the shaft. Thus the shaft may revolve about its center of gravity, and this oil bearing serves the same purpose as the De Laval flexible shaft.

At P is shown a by-pass valve by means of which live steam may be admitted to the space E, if desirable. Of course this reduces one stage of the expansion, with a corresponding loss of economy, but will increase the power of the turbine. If the condenser fails on a condensing turbine it may still be run at full load by opening the by-pass valve.

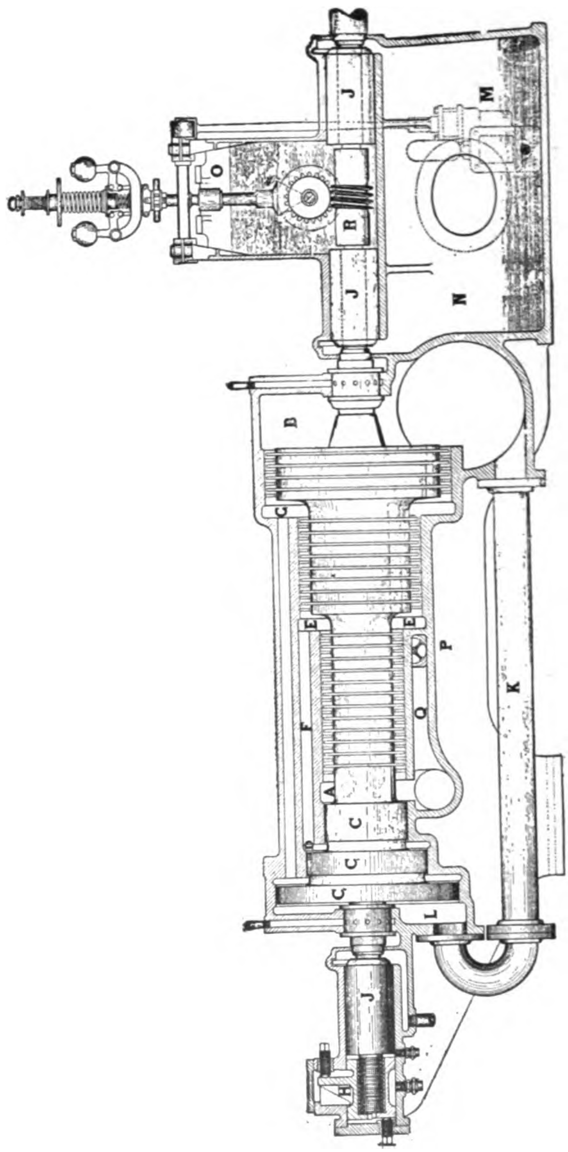


Fig. 52.

Steam is admitted to this turbine in puffs through a reciprocating valve. A fly-ball governor regulates the admission, which is always at boiler pressure.

For electric generators the turbine has many advantages, among them high speed and direct connection. They have small foundations and take up little space; there is slight loss from friction and few parts. Where slow speed is desired a reciprocating engine is probably the best.

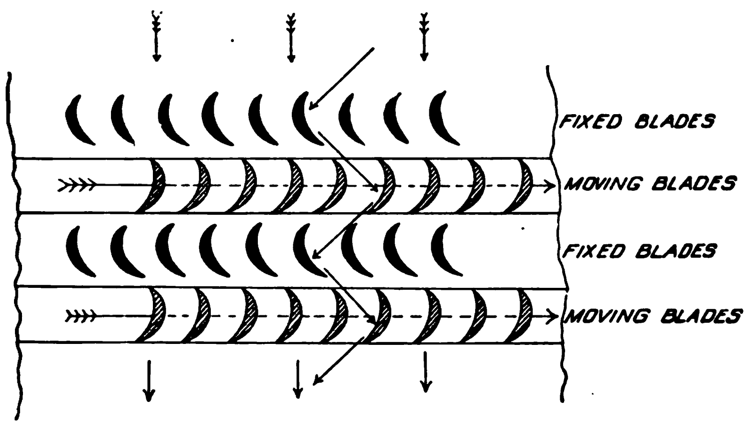
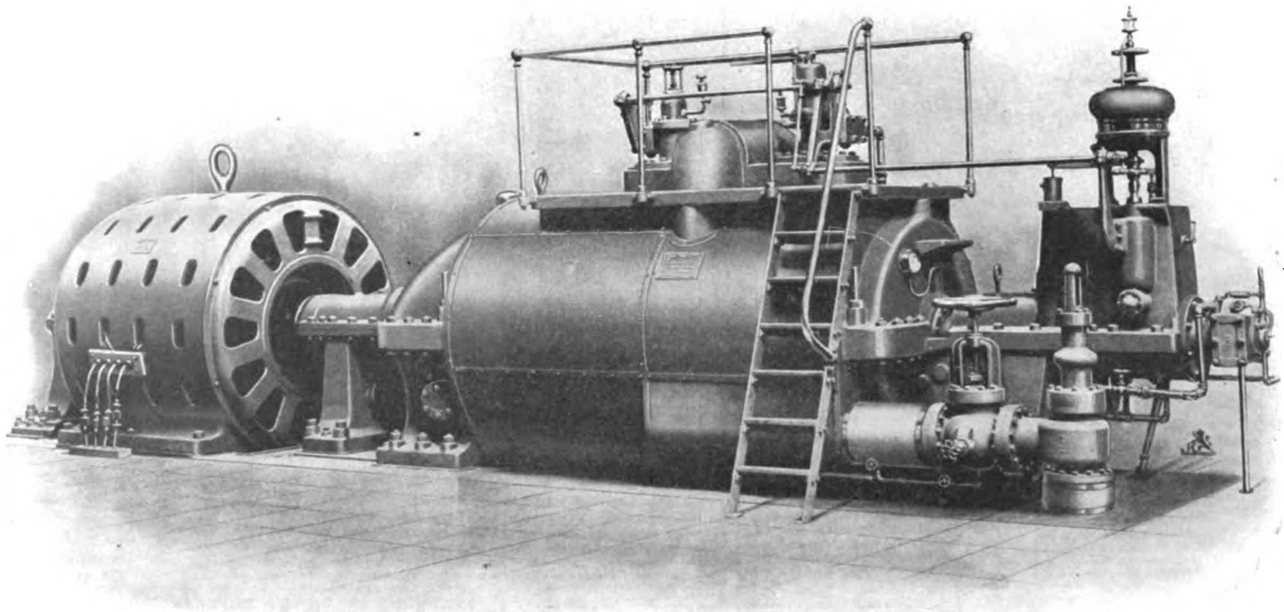


Fig. 53.



WESTINGHOUSE-PARSONS TURBINE-GENERATOR UNIT OF 1,000-KILOWATT RATED CAPACITY AS IT APPEARS WHEN INSTALLED.

THE STEAM TURBINE.

The principle of the Curtis turbine differs from that of any other type in that it permits the use of moderate rotative speeds and very compact and simple mechanism. The turbine is divided into stages, each of which contains one, two, or more, revolving

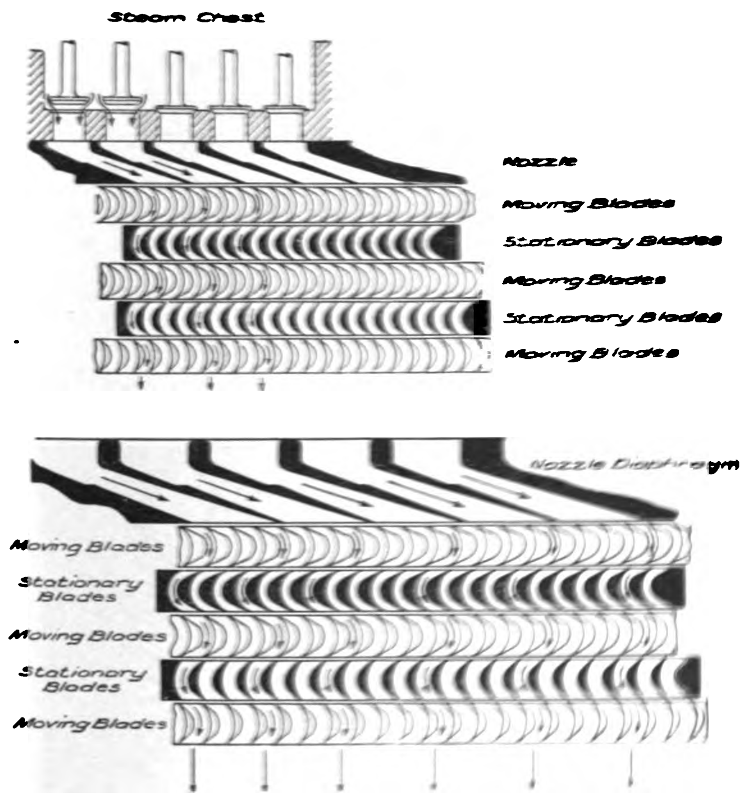
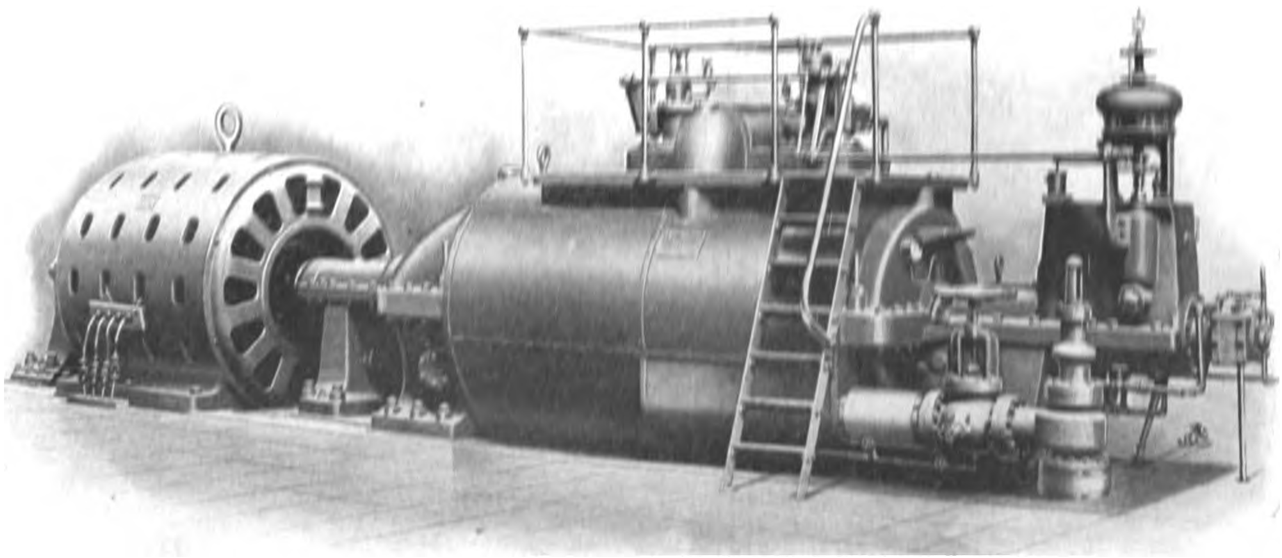


DIAGRAM OF NOZZLES [illegible]

buckets supplied with [illegible] As the work is divided into [illegible] velocity in each stage is reduced, thereby [illegible] more efficient and perfect than is [illegible] velocity is imparted. The divi[illegible] arranged to utilize the largest [illegible] of ex[illegible]sion. The position of [illegible] relation to the nozzle [illegible]



WESTINGHOUSE-PARSONS TURBINE-GENERATOR UNIT OF 1,000-KILOWATT RATED CAPACITY AS IT APPEARS WHEN INSTALLED.

THE STEAM TURBINE.

The principle of the Curtis turbine differs from that of any other type in that it permits the use of moderate rotative speeds and very compact and simple mechanism. The turbine is divided into stages, each of which contains one, two, or more, revolving

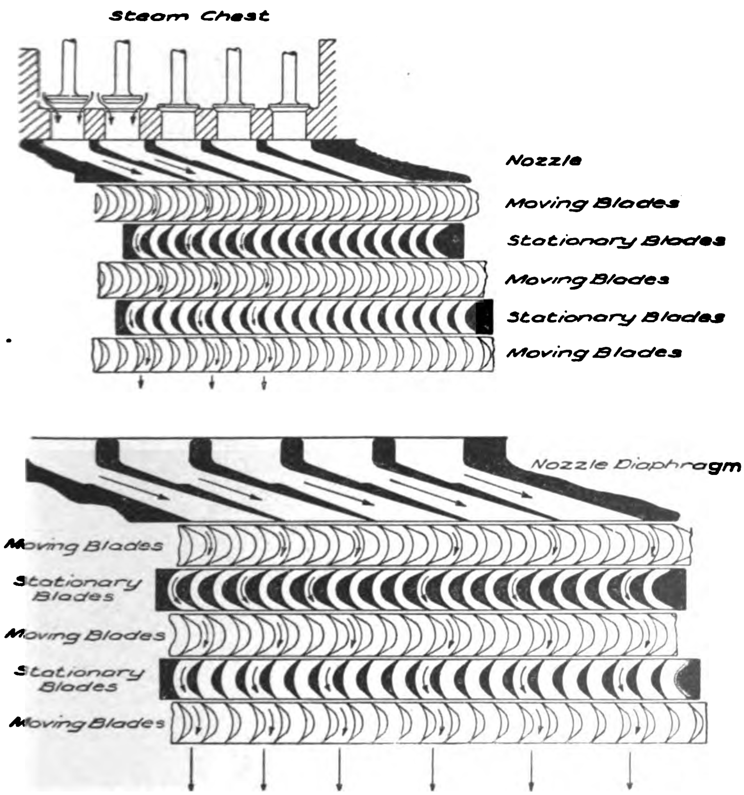
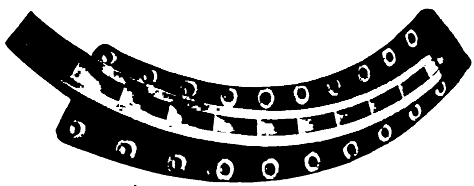


DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE.

buckets supplied with steam from a set of expansion nozzles. As the work is divided into several stages, the nozzle velocity in each stage is reduced, thereby rendering the nozzle action more efficient and perfect than is possible where a higher initial velocity is imparted. The division of pressure between the stages is arranged to utilize the largest possible proportion of the energy of expansion. The position of the moving and stationary buckets with relation to the nozzle is shown in the accompanying diagram.

Vertical Type. For turbines of large capacity the General Electric Company has applied these principles to a turbine with a vertical shaft, to avoid all imposition of weight on cylindrical bearings and tendency to shaft deflection as well as all difficulties due to irregularity of expansion or imperfections of support. The turbine is compact and of the greatest mechanical simplicity.

Step-Bearing. The step-bearing at the end of the vertical shaft supports the revolving part and maintains the revolving and stationary elements in exact relation. It consists of two cylindrical, cast-iron plates bearing upon each other and with a central recess to receive the lubricating fluid, which is forced in by pumps with a pressure sufficient to sustain the weight of the revolving part. It is apparent that the entire weight of the machine is thus carried upon a film of lubricating fluid and that there is no appreciable friction. When the flow of liquid is interrupted, the bearing is slowly worn away, but experience has shown that interruptions in the flow seldom cause any deterioration which prevents the continuance of the machine in service after the flow is re-established. The tendency of the bearing in such cases is to wear itself to a new surface so that it operates normally.

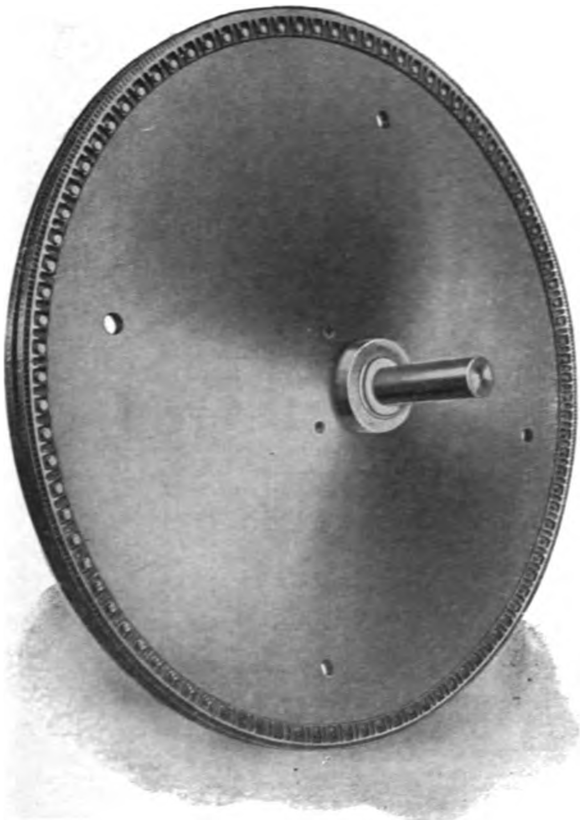


NOZZLE.

All large steam turbines are necessarily dependent upon forced lubrication. Failure of lubrication in a horizontal turbine is liable to cause serious trouble through cutting of the shaft or interference with the alignment. In the Curtis vertical type the possibility of any trouble is minimized and the simple cast-iron blocks can readily be replaced at trifling expense. In large stations, where several turbines are operated, it is desirable to install weighted accumulators which will maintain a constant pressure and also act as a reserve.

Clearances. In consequence of the exact relation maintained between the revolving and stationary elements by the step-bearing, it is possible to operate the turbines with very small clearances between the moving and stationary buckets. Experience, how-

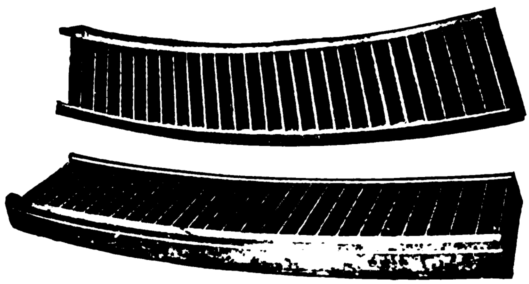
ever, has shown that the reduction of clearance beyond a certain point, is not beneficial, and that clearances less than those which are desirable for economical reasons can be used without mechanical difficulty.



REVOLVING WHEEL FOR 500 KW. CURTIS STEAM TURBINE.

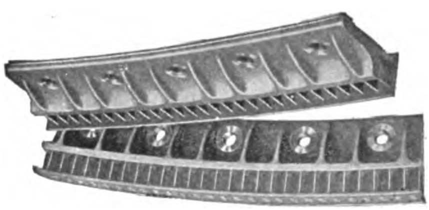
Balance. A most important matter in all steam turbine work is the balance; and the importance of good balance applies as well to vertical turbines as those that are operated in a horizontal position. When the balance is good, the bearings on the vertical turbine shaft are practically free from strain or friction. It is possible to operate these machines successfully with a considerable imperfection of balance, but a perfect balance is practicable and should be attained in every case.

Governing. The speed of these turbines with variable load is controlled by the automatic opening and closing of the original admission nozzle sections. A centrifugal governor, attached to the top of the shaft, imparts motion to levers which in turn work the



STATIONARY BUCKETS FOR CURTIS STEAM TURBINE.

valve mechanism. There are several valves, each communicating with a single nozzle section, or in some cases two or more nozzle sections. These valves are connected to long pistons, by which the valve can be opened or closed by steam. The motion of each of these pistons is controlled by a small pilot valve which is worked by the governor mechanism. The movement of the governor mechanism moves the pilot valves successively and the main valves are opened or closed by the steam. By suitable adjustment, almost any degree of accuracy in speed control is obtainable.



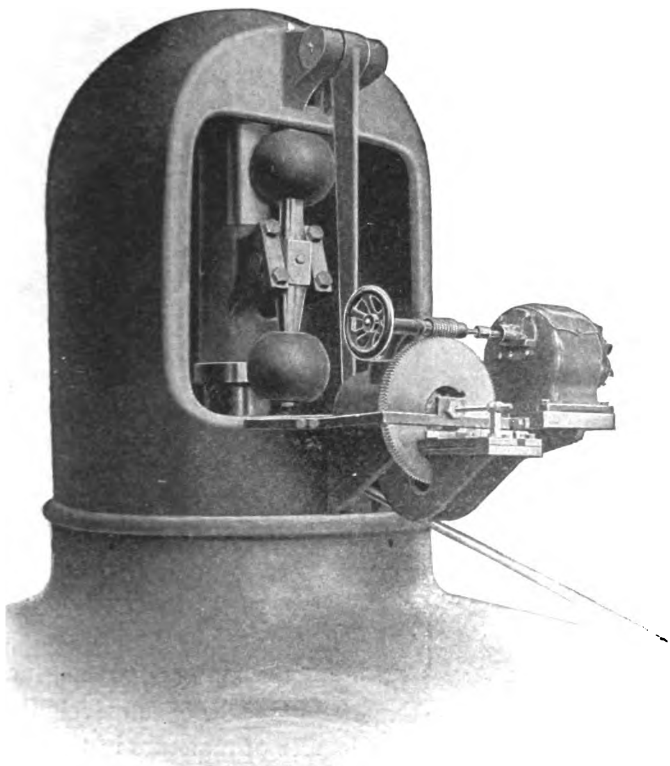
REVOLVING BUCKETS FOR CURTIS STEAM TURBINE.

The steam consumption of turbines is naturally dependent upon speed, size, and other conditions, and varies in different individual designs. Machines of this type show excellent results as compared with other turbines and engines, the light-load and overload efficiency being a marked advantage. The guarantees of steam economy made by the General Electric Company are based upon results obtained with machines in operation.

Condensers. The larger sizes of Curtis turbines are designed to operate condensing, but they are all adapted to operate non-

condensing, and when thus operated will carry full rated load. These turbines are designed to utilize the expansion of the steam to a high degree of vacuum, and the use of good condensing facilities is therefore desirable.

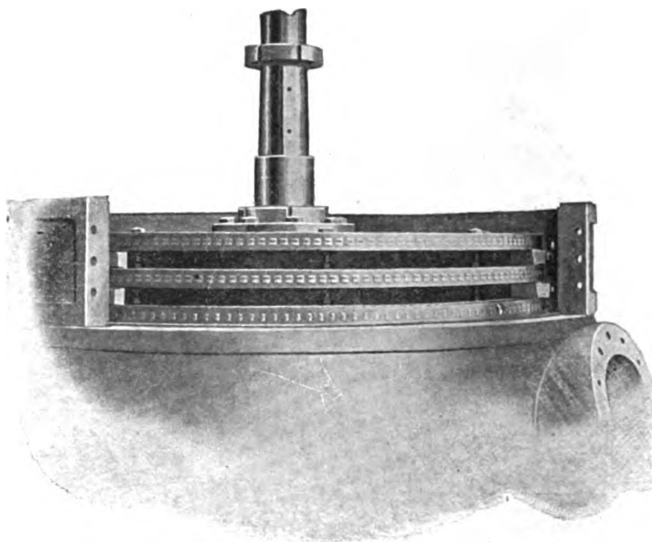
When surface condensers are used, the condensed water can be returned directly to the boilers, as it is entirely free from oil.



GOVERNOR FOR 5000 KW. TURBINE.

Experience shows that distilled water free from air has no bad effect on boilers. The possibility of so returning water is of the greatest practical value, since deterioration of boilers and inefficiency, through dirt and scale, are serious sources of expense in many power stations. In some types of steam turbines, oil is introduced in connection with balancing pistons or steam packing, and therefore this great advantage cannot be realized.

Pressure and Superheat. In these turbines steam is expanded to a considerable degree before it reaches the first buckets. High temperature in the steam is therefore not a source of practical difficulty, and steam of very high pressure and high degree of superheat can be used. The reduction in steam consumption by superheat or increased pressure is as great in the Curtis turbine as in any form of steam engine.



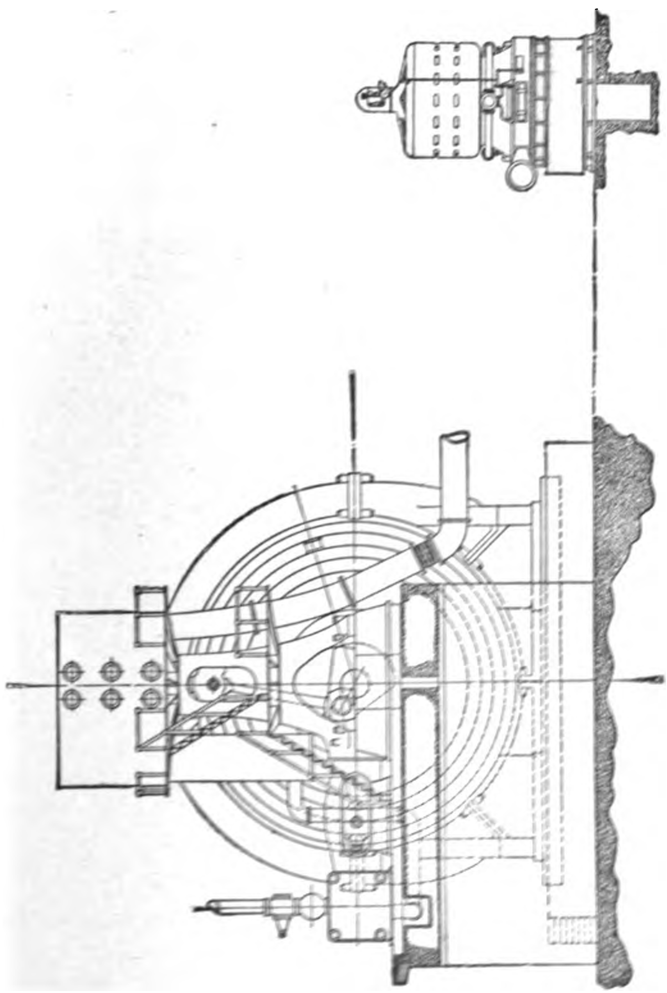
500 KW CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION.

Wear on Buckets. The question is sometimes raised as to the rate of deterioration through erosion of the buckets in the Curtis Steam Turbine. Experiments show conclusively that while the wear varies with different degrees of moisture in the steam and with different degrees of steam pressure, it is in any event negligible from the standpoint of maintenance. All buckets in the Curtis turbine can be renewed without difficulty and at small expense. In the lower pressure stages, where the density of the steam is less, no wear has been perceptible.

Applications. The speeds adopted for the Curtis turbines are such as to give the best results in the design of the generators, consequently the General Electric generators designed for operation with turbines have high efficiency, and are so proportioned that

they will carry heavy overloads without injurious heating. These turbines are built in sizes ranging from $1\frac{1}{2}$ Kw. to 5,000 Kw.

The Curtis turbine is also suitable for driving centrifugal

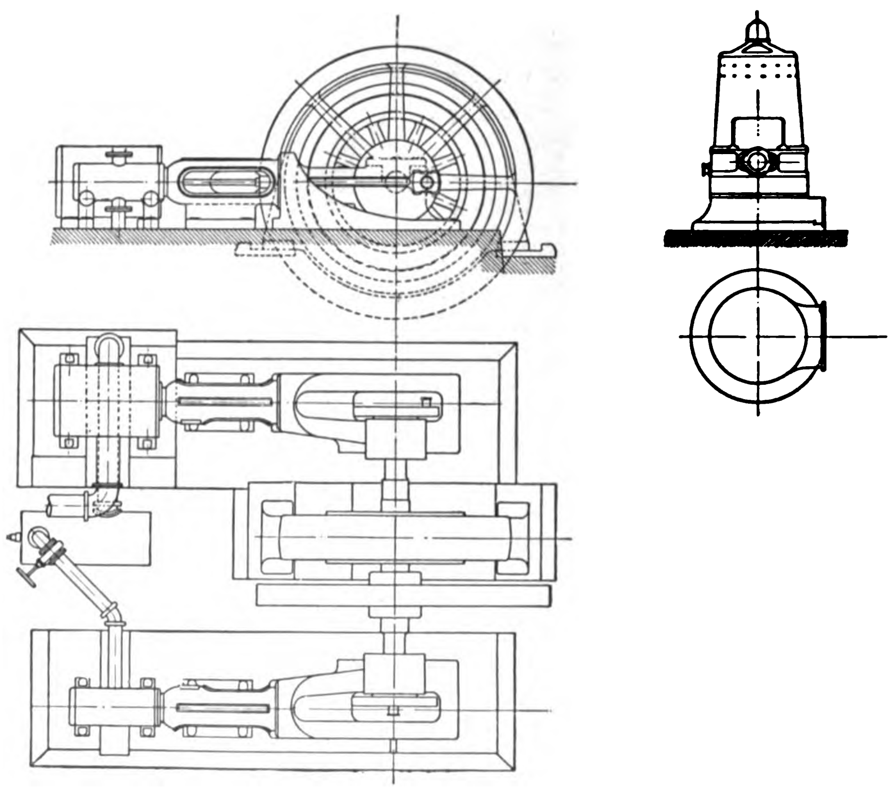


COMPARISON OF 500 KW. CORLISS ENGINE AND 500 KW. CURTIS TURBINE.

pumps, blowers, fans, and other similar apparatus. The uses for such applications are being rapidly developed. In order to meet the demand for small direct-current turbines to be used for exciters, train lighting, and isolated lighting a complete line of non-condensing horizontal shaft turbines has been developed, ranging

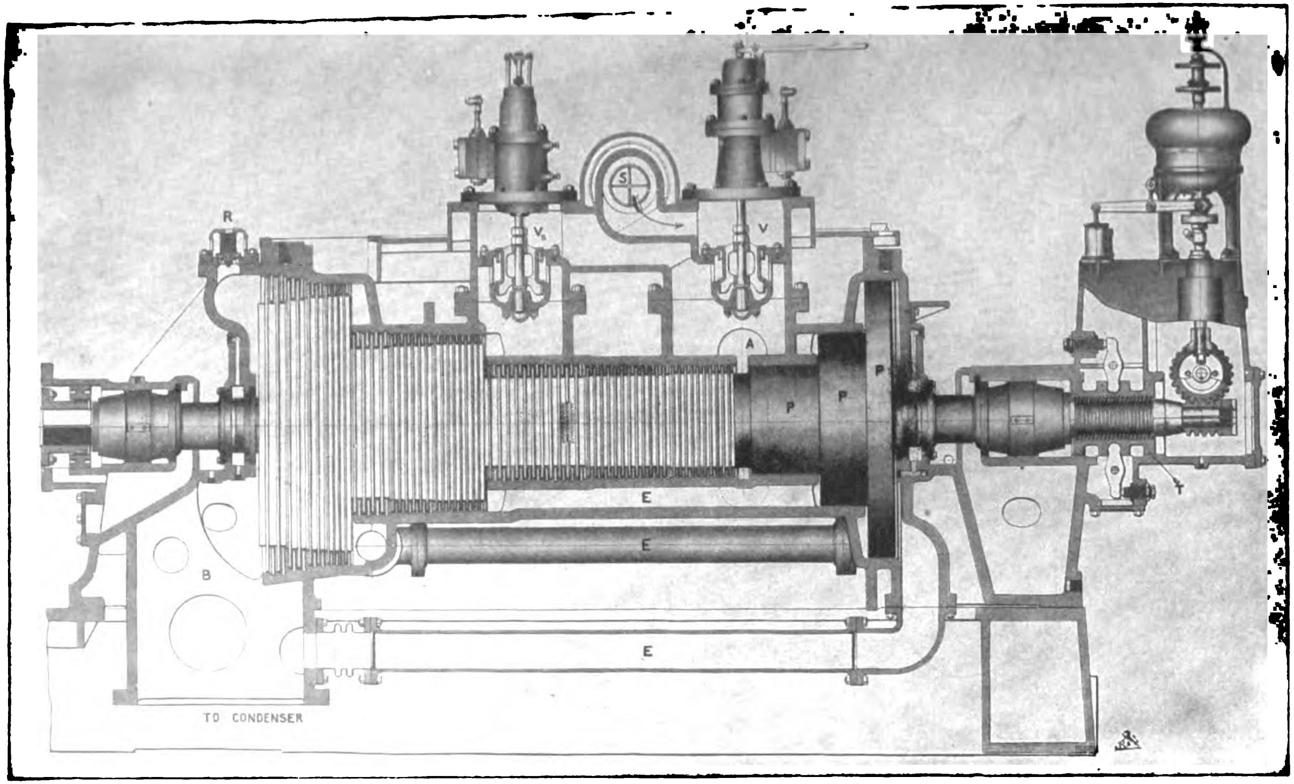
in capacity from 1½ Kw. to 300 Kw. These machines are designed to operate at low shaft speed without the use of gearing and show relatively high steam economy when operating non-condensing. They are self-contained and are automatic in regulation.

The machine shown in the accompanying diagram has been tested under a variety of conditions at Newport, and has given



COMPARISON OF 500 KW CROSS-COMPOUND ENGINE AND 500 KW. CURTIS TURBINE.

results which illustrate very well the advantage of this type. Among other tests that were made, the machine was operated on a rapidly changing railway load; the momentary variations of load amounting to about 120 Kw. In one test the average load carried with this fluctuation was 250 Kw., and the steam consumption was 24.4 pounds per Kw. hour output, with saturated steam. Another



SECTIONAL ELEVATION OF A TYPICAL WESTINGHOUSE-PARSONS STEAM TURBINE.

test was one with similar fluctuations and with an average of 421 Kw. The steam consumption under this condition was 20.7 pounds of saturated steam per Kw. hour output. The best reciprocating engine under conditions of the first test would probably consume from 28 to 30 pounds per Kw. hour.

The Westinghouse-Parsons Steam Turbine operates on the principle that steam expanding through a definite range of temperature and pressure exerts the same energy whether it issues from a suitable orifice or expands against a receding piston.

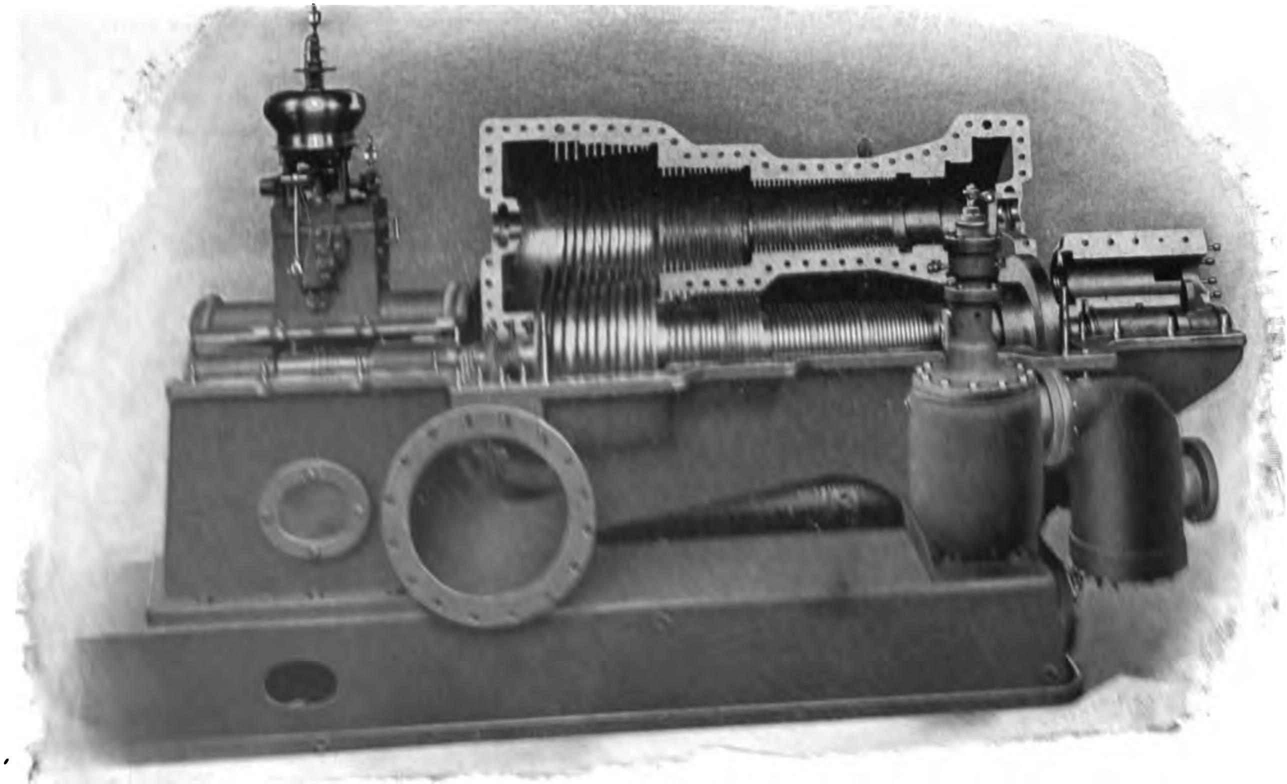
Two transformations of energy take place in the steam turbine; first, from thermal to kinetic energy; second, from kinetic energy to useful work. The latter alone presents an analogy to the hydraulic turbine. The radical difference between the two turbines lies in the low density of steam as compared with water, and the wide variation of its volume under varying temperatures and pressures.

A typical Westinghouse-Parsons turbine is shown in section in the illustration.

The steam volume progressively increases from inlet A to exhaust B in the annular space between the rotating spindle and the cylinder walls. The entire expansion, which is approximately adiabatic *, is carried out within this annular compartment which essentially resembles a simple divergent steam nozzle. There is this difference, however, that whereas in a nozzle the heat energy of the working steam is expanded upon itself in producing high velocities of efflux, in the Westinghouse-Parsons turbine the total energy, due to expansion between pressure extremes, is subdivided into a number of steps. In each step the dynamic relationship of jet and vane is such as to secure a comparatively low average velocity from inlet to exhaust, this generally varying from 150 feet per second as a minimum at the high pressure end to about 600 feet per second as a maximum at the low pressure end.

The result is of the utmost importance. With high steam velocities, excessive surface speeds are encountered, causing serious losses from fluid friction and rapid deterioration of parts from erosion. With low steam velocities, commercial speeds are readily obtained, friction loss is greatly reduced, and the depreciation of

* No heat is taken in or given out by the steam.



600 HORSE-POWER TURBINE OPEN FOR INSPECTION

the turbine from practically the only source of wear becomes inappreciable.

The expansion of steam at any one element is typical of its working throughout the turbine. Each element consists of a ring of stationary and a ring of moving blades. The former give direction and velocity to the steam; while the latter immediately convert the energy of velocity into useful torque. The total torque upon the shaft is due both to impulse of steam entering the moving blades and to reaction as it leaves them.

A condensing steam turbine in operation affords a striking example of the conversion of heat into work. The temperature of the cylinder falls, within a distance of three or four feet, from 365 degrees Fahrenheit at the high pressure end to 115 degrees at the exhaust end, when working with 150 pounds of steam pressure and 27 inches vacuum. These temperatures remain constant during operation. There is no alternate condensation and re-evaporation as in the piston engine.

Construction. The Westinghouse-Parsons turbine in effect consists of but two essential elements—a casing, stator or stationary part, and a rotor or rotating part. A brief detailed description follows:

Rotating Element. The rotating element is built up of cast-steel drums carrying rows of blades or vanes, these being mounted on a steel shaft. These drums are arranged in three steps of increasing diameters, but the selection of three diameters is merely for mechanical convenience. Provision for the proper expansion of the steam might be made whether there be one or several diameters. If, however, a speed and diameter of rotor be selected that would permit of a convenient size of blades at the outlet, those at the inlet would become inconveniently small, and *vice versa*. By varying the drum diameters at several convenient points, the proper velocity relations between steam and vane may be preserved, and at the same time the number of different sizes of blades may be reduced to a minimum.

Opposed to the three sets of blades the spindle also carries three rotating balance pistons P, each of such diameter as to exactly balance, by means of the passages E, the axial thrust of the steam against its corresponding drum of blades. These balance pistons

revolve within the cylinder with a close fit, but are not in mechanical contact. The adjacent surfaces are provided with frictionless packing rings which offer so devious a path for the steam as to make leakage past them inappreciable. The shaft also carries a small thrust, or, more properly, adjustment bearing T, whose sole function is to maintain the normal mechanical clearances between the rotating and stationary blades. These clearances may be conveniently large without lowering the efficiency. In actual practice they are never less than one-eighth inch, and in large blades are as much as one inch.

Casing or Stationary Element. The interior proportions of the casing conform to the several diameters of the rotor and its parts. Around its inner surface are fixed rings of blades which alternate in position with the rings of revolving blades upon the rotor, and are of reverse pitch. The cylinder is divided along a horizontal plane so that by simply lifting the cover all the working parts are exposed to view.

Blades. The precise curvature and arrangement of the blades is the result of both theory and exhaustive experiment. The blades are so assembled as to admit of great ease of repair, and by a calking process which holds them so firmly to the body of the rotor that they will pull in two before they can be drawn out by force.

Glands. Frictionless glands are provided at the ends of the casing or stator to prevent the escape of steam or the influx of air into the turbine at the point of entry of the shaft. Air leakage is particularly detrimental in cases where it is desirable to maintain a high vacuum. The water-sealed glands used in the Westinghouse-Parsons turbine effectively prevent this leakage, and, further, require no lubrication. It is impossible for any oil from the bearings or the lubricating system to find its way into the steam spaces. There are no rubbing surfaces in these glands, and experience has demonstrated that wear is negligible. The water used for sealing them is small in quantity and is not wasted, as, after serving its purpose, it may be returned to the feed-water system.

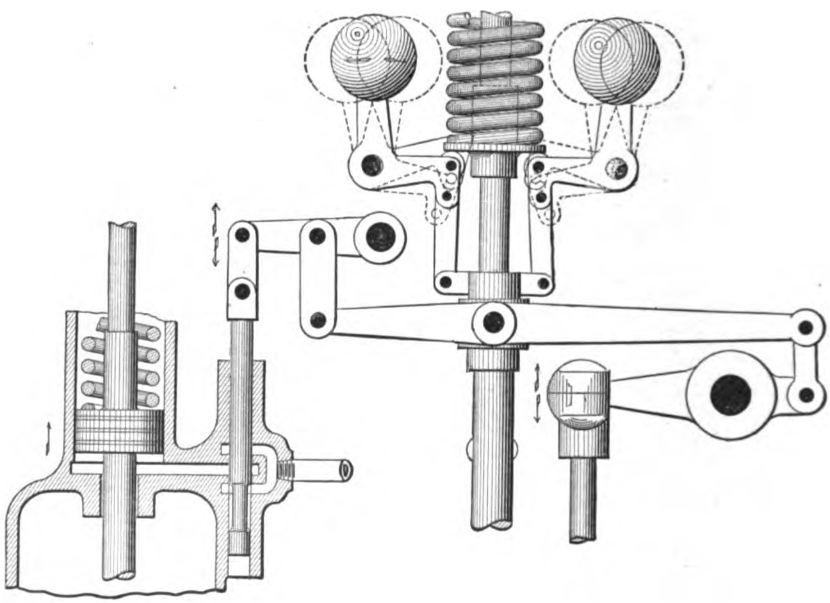
Bearings. In turbines of moderate size and therefore of relatively high rotative speeds, flexible bearings are employed in

order to permit the spindle to revolve upon its gravity instead of its geometric axis. This expedient is desirable to absorb the vibration which occurs while the turbine is passing its critical speed. The bearing consists of a nest of loosely fitting concentric bronze sleeves with sufficient clearance between them to insure the formation of oil films. These form cushions, permitting a certain amount of vibration of the shaft, but at the same time absorbing and restraining it within narrow limits. In the larger sizes of turbines, however, and in fact for all machines running below 1,200 revolutions per minute, the flexible bearing is not necessary. Instead, a split self-aligning bearing, lined with anti-friction metal, is used as in ordinary forms of moderate speed machinery.

Lubrication. In the Westinghouse-Parsons turbine the bearing surfaces are so liberally proportioned that the entire weight of the rotating element is supported upon a fluid film of oil through capillary action alone, and without the use of oil under high pressures. A small pump driven from a worm gear upon the shaft circulates oil through a closed lubricating system, comprising in the order of their arrangement—pump, oil cooler, bearings and reservoir. The oil is always supplied to the bearings at the point of least pressure; that is, at the top of the shell, from which it is distributed around the shaft. The pressure upon the fluid films is due simply to a static head of one to three feet of oil sufficient to insure thorough flushing of the bearings. It is probable that the shaft never comes in actual contact with the bearings but is separated by the oil film, as is evidenced by the preservation of the original tool marks upon the interior of the shell after years of use.

Governor. Steam enters the turbine in puffs, not in a continuous blast. Speed regulation is, therefore, accomplished by proportioning the duration of the puffs to the load. This is done by means of a small pilot valve actuated directly by the governor and which controls the steam supply through the main poppet admission valve. When the turbine is in operation the main poppet valve is continually opening and closing at uniform intervals, but the periods during which the valve is allowed to remain open are proportioned to the load on the turbine. At light load

the valve opens for a very short period and remains closed during the greater part of the interval. As the load increases the period lengthens, until finally, at about full load, the valve does not reach its seat at all and continuous pressure is obtained in the high pressure end of the turbine. On the load becoming further increased an auxiliary or secondary valve begins to open and to admit steam to the annular space at the beginning of the intermediate drum of the rotor where the working steam areas are



DIAGRAMMATIC ARRANGEMENT OF GOVERNOR MECHANISM.

greater. This increases in proportion the total power of the turbine. The operation of this secondary poppet valve is the same as that of the main admission valve, so that the governor automatically controls the power and speed of the turbine from no load to such overloads as are usually beyond the limits of generating apparatus built on normal ratings. The turbine also operates at its *best economy* at or near full rated load, although possessing at the same time large overload capacity with remarkably high efficiency.

The governor is of the fly-ball type, the ball levers being mounted on knife edges instead of pins to secure sensitiveness.

The speed of the turbine while running may be varied within the limits of the governor spring by grasping the knurled hand wheel at the top, when the spring and tension nuts may be brought to rest. Adjustment of the spring tension may then be made. This feature is particularly useful for synchronizing the speed of alternating current generators operating in parallel and for distributing the load between them when so operated. The figure shown illustrates diagrammatically the connection between the governor and the pilot valve. Variations in the speed change the height of the fulcrum of the lever on the governor spindle, which in turn varies the throw of the pilot valve relatively to the valve port. This controls the main valve and steam admission as above stated. Reciprocating motion necessary to operate the mechanism originates in an eccentric driven by the turbine from a worm on the main shaft.

Speed Limit. On the larger size turbines an automatic centrifugal speed limit governor is provided which instantly shuts off the steam supply if a predetermined excess of speed above normal should be reached.

Coupling. A flexible sleeve coupling connects the turbine to its generator. Either machine may thus be dismantled without disturbing the remaining adjustments.

The De Laval Steam Turbine, which dates back to 1882, and lays claim to be the pioneer of practical steam turbines, was first constructed by Dr. Gustaf de Laval, of Stockholm, Sweden. His first turbine was of the reaction type and was used in conjunction with his world-famous Cream Separator. In 1888 he built a turbine of the single impulse, free jet type, which differs only in improvement from the engines of the present time. The De Laval turbine has only one set of vanes, and one set of expanding nozzles, in which the complete expansion of the steam takes place in one operation, resulting in a high velocity jet.

The kinetic energy of the jet is successfully utilized by using high vane speeds, easily attained by mounting the turbine wheel, which is of special design, to withstand the centrifugal strains developed at that speed, on a flexible shaft, *i.e.*, a shaft of such dimensions as will allow of the wheel rotating about its center of mass, in place of its center of sphere. This, the "critical speed", usually takes place at about one-sixth of the rated speed. The

object attained is that all vibrations due to unequal balancing disappear on reaching this point. It can be noted by anyone who is starting up a De Laval turbine, by the sudden quieting which takes place.

The velocity of the steam jet being given, and with the nozzles at an angle of 20 degrees to the plane of the buckets, the velocity of the turbine wheel should be 47% of the velocity of the steam. The absolute velocity of the steam leaving the buckets is then 34% of the initial velocity, and the formula $\frac{29 \times 550 \times 3,600}{V^2 - V_3^2}$ where V and V_3 are, respectively, the initial and final velocities, will give the theoretical steam consumption. With an initial velocity of 4,000 ft. per sec. this would be 9.1 lbs. per horse-power.

Practical considerations, however, confine the De Laval wheel to a lower peripheral speed, *i.e.*, about 1,380 ft. per sec., in place of 1,880, as it should be in the case just given. This gives a theoretical consumption of 9.8 in place of 9.1.

The buckets are separately drop-forged, and are fitted into the wheel by means of a bulb shank fitting into a corresponding slot milled in the wheel.

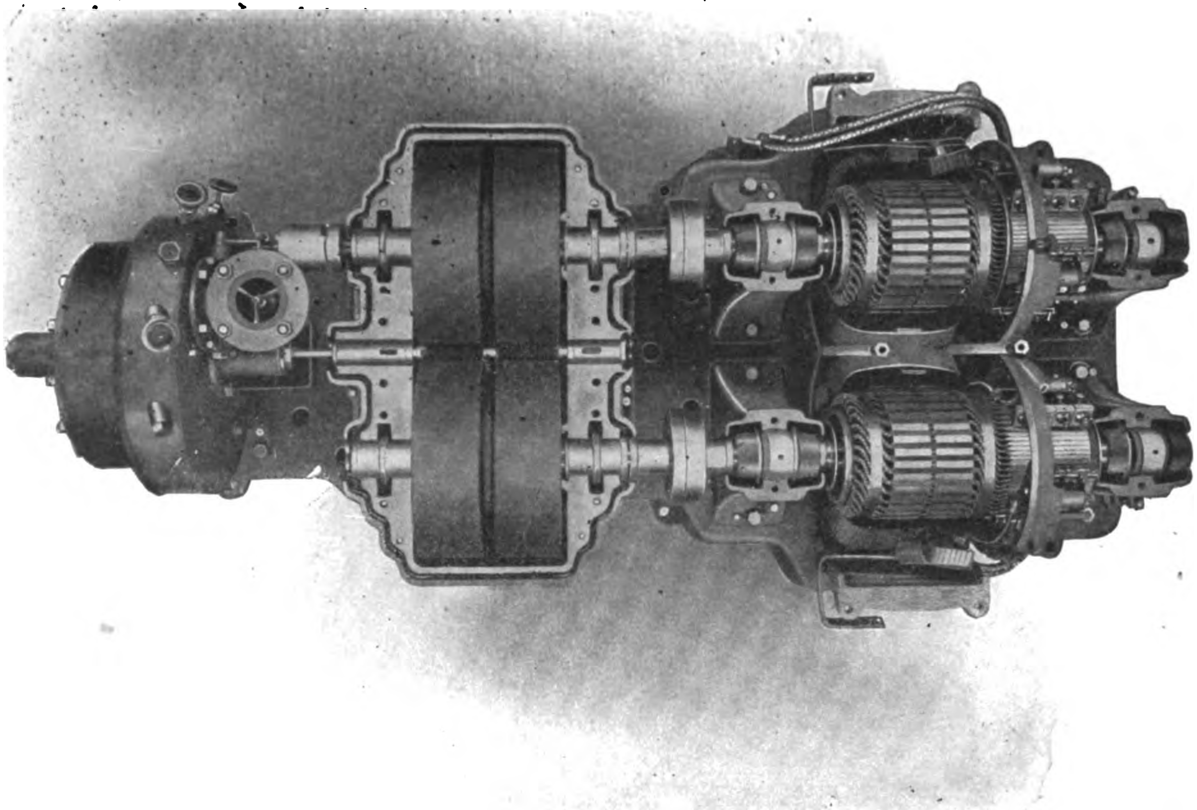
The steam nozzles are of bronze, except where high superheat is used, when nickel steel is substituted. The nozzle section naturally varies with the steaming conditions, *i.e.*, high or low vacuum, and high or low steam pressures, a greater divergence being allowed for the high pressures and high vacuums.

By closing some of these nozzles on a steady light load, the throttling effect of the steam is so decreased as to give excellent efficiencies on light loads.

The gearing is of helical design, as is seen in the accompanying figure, which shows a 110 H.P. turbine dynamo with upper half of gear case and field frame removed.

The high speed shaft bearings are all lined with special high speed metal, and are oiled by gravitation feed, the oil being used over and over in continuous cycle. The low speed bearings are oiled automatically by rings.

The speed governing is performed by a centrifugal governor placed on a low speed shaft and operating on a balanced valve.



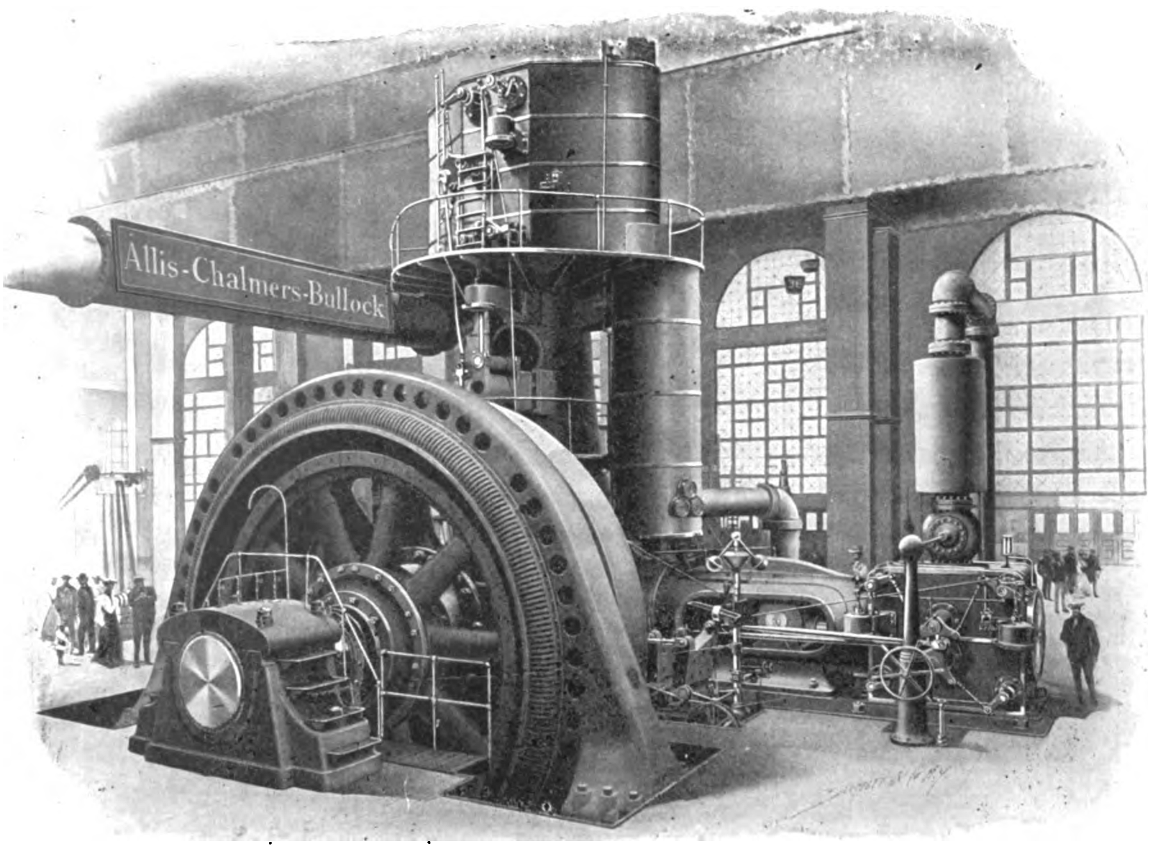
110 H.P. TURBINE DYNAMO—UPPER HALF OF GEAR CASE AND FIELD FRAME REMOVED.

In addition to this means of control, an air valve is placed on the wheel case, operated by the governor above a certain speed, admitting air into the wheel case and thereby producing a braking effect on the wheel.

The material used in the construction of the De Laval turbine is only of a high grade. The wheel case is of cast steel; the turbine wheel and shaft of forged nickel steel; the gear wheels of cast iron, with a mild steel rim put on by hydraulic pressure.

The De Laval steam turbine is used on all forms of high speed work, and is especially adaptable for direct connection to electric generators (both alternating and direct current), for centrifugal pumps, and for air or gas blowers.

The De Laval steam turbine will work under all existing conditions from 60 lbs. non-condensing up to 250 lbs. and over, condensing; the nozzles naturally being made to suit the particular conditions.



5,000 H.P. ALLIS-CHALMERS ENGINE. DIRECT-CONNECTED TO GENERATOR.

Carries 5,600 H.P. with 15 inches vacuum.

Machinery Hall, World's Fair, St. Louis.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.
B. The Inspection and Testing.
C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the

bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine

* NOTE. By resistance measurements.

firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

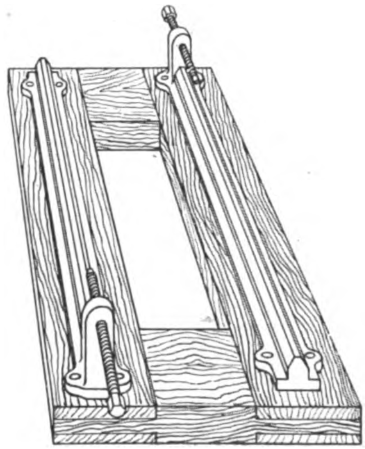


Fig. 1.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig, 2. The bolts are preferably surrounded by iron

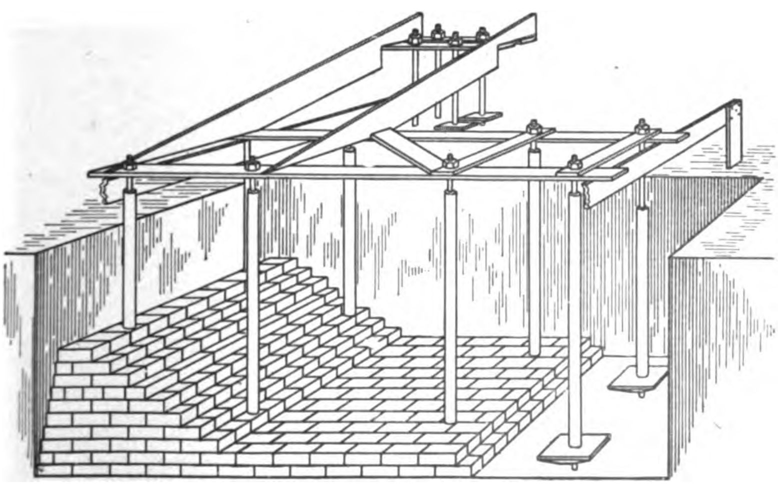


Fig. 2.

pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This

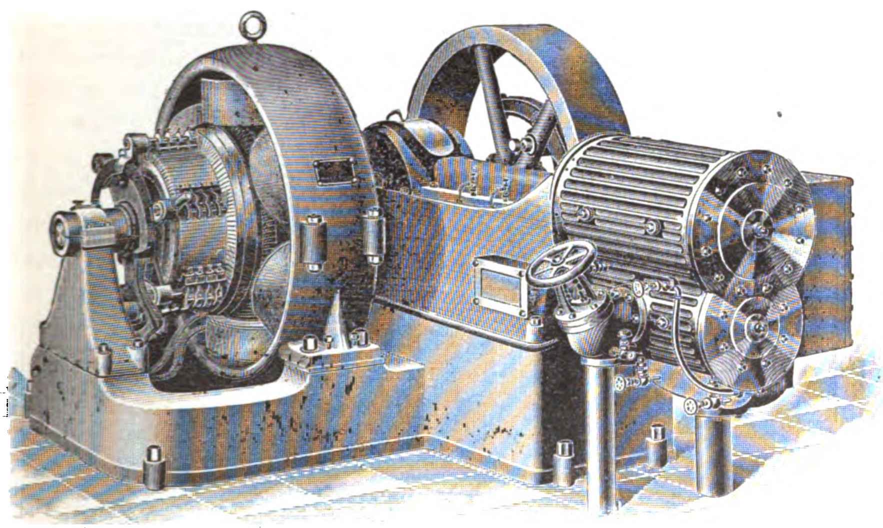


Fig. 3.

method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several

ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

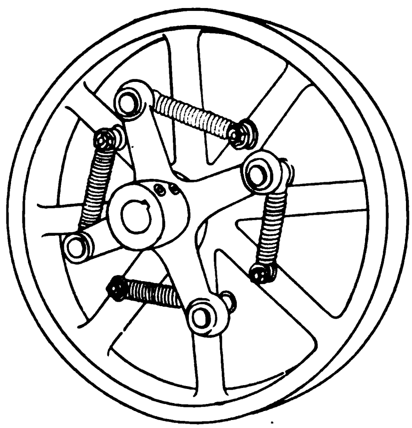
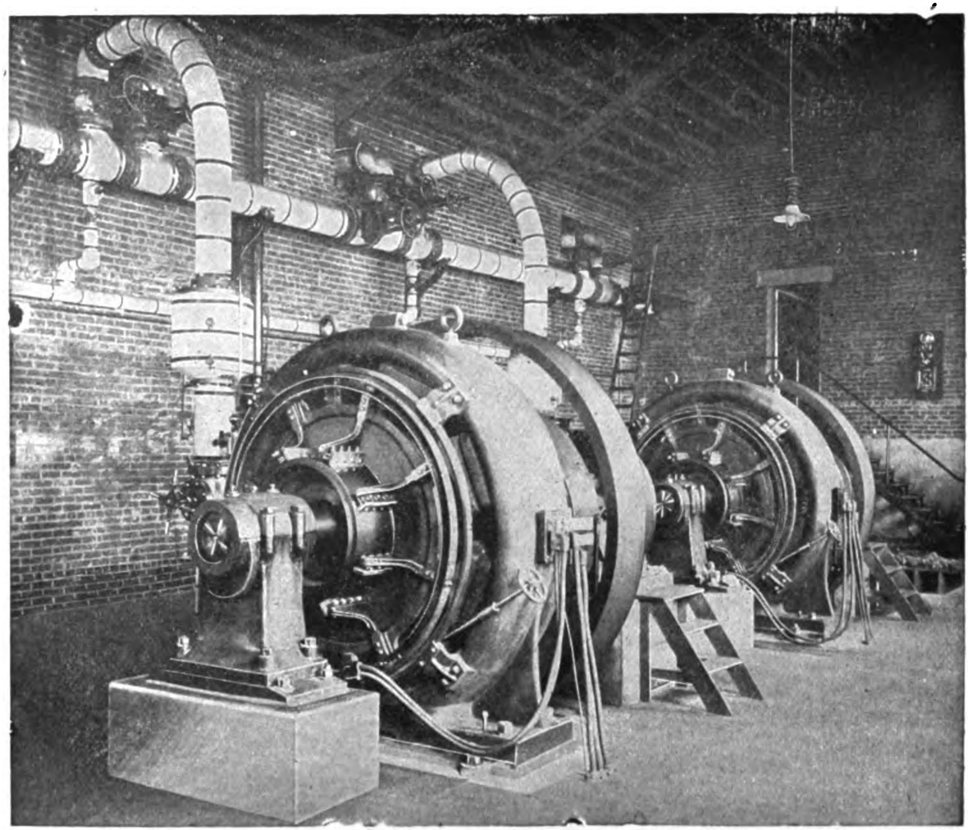


Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected,



DIRECT-CONNECTED GENERATORS
Operating the Largest Woodworking Plant in the United States.
Triumph Electric Company.

one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top*. If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{H. P. \times 1,000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

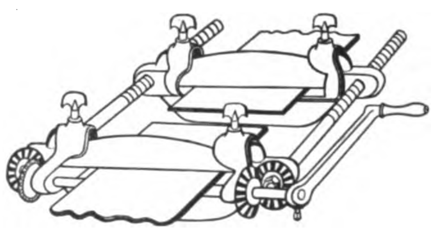


Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the

* NOTE. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as $\frac{1}{2}$ inch per foot of length.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift

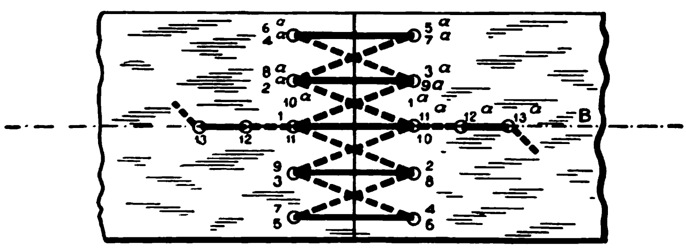


Fig. 6.

sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about $\frac{3}{4}$ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this pur-

pose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \dfrac{V^2}{1{,}072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In

the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from

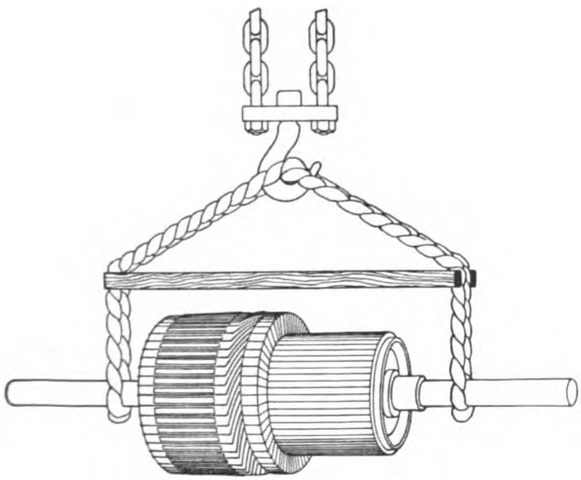


Fig. 7.

which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.*:

Exposed on	Cleats. Knobs. Bushings.
Concealed in	Wooden moulding. Iron conduit. Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed $\frac{1}{2}$ per cent at full load, because it interferes with proper

regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos. 16 and 18, B & S. gage wire is given, but no smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit. will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

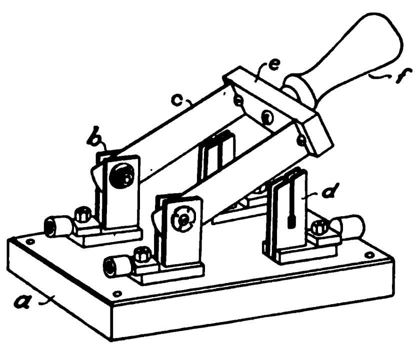


Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessibie places and grouped as far as possible If located in ex-

posed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
125 VOLTS OR LESS:		
For Switchboards and Panel Boards—		
10 amperes or less	¾ inch	½ inch.
11-25 "	1 "	¾ "
26-50 "	1¼ "	1 "
For Individual Switches—		
10 amperes or less	1 inch	¾ inch.
11- 35 "	1¼ "	1 "
36- 100 "	1½ "	1¼ "
101- 300 "	2¼ "	2 "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "
126 TO 250 VOLTS:		
For all Switches—		
10 amperes or less	1½ inch	1¼ inch.
11- 35 "	1¾ "	1½ "
36- 100 "	2¼ "	2 "
101- 300 "	2½ "	2¼ "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters "A. C."

251 TO 600 VOLTS:		
For all Switches—		
10 amperes or less	3½ inch	3 inch.
11- 35 "	4 "	3½ "
36-100 "	4½ "	4 "

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches, must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible

Fig. 9.

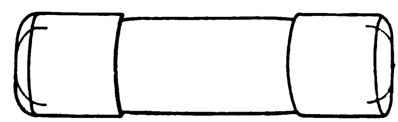


Fig. 10.

alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and

the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their

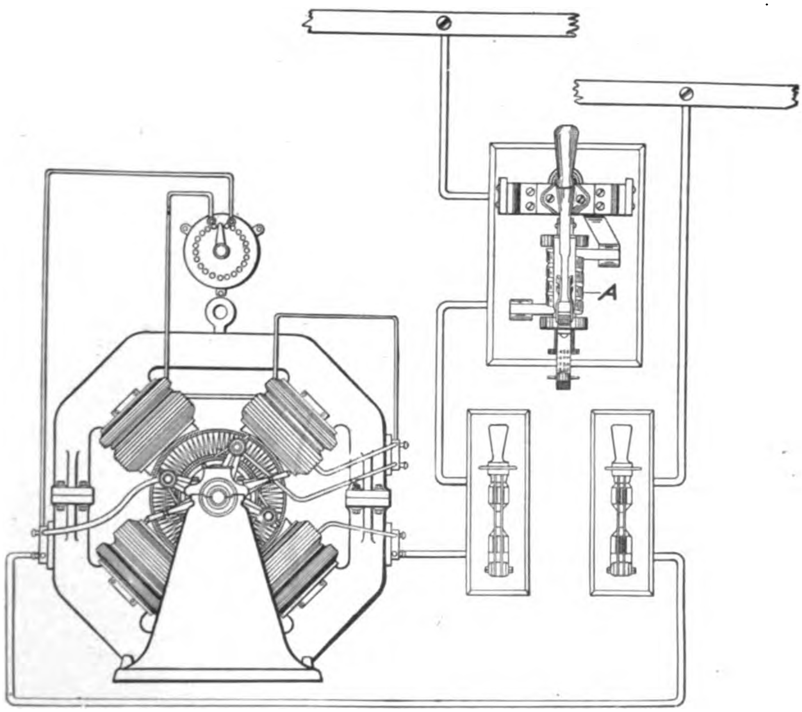


Fig. 11.

general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.

4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows :

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2- or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant - Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils S*h* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

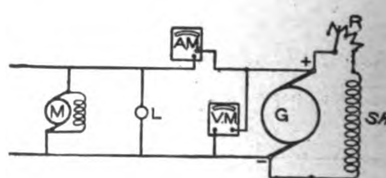


Fig. 12.

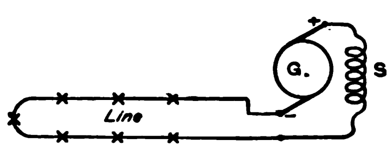
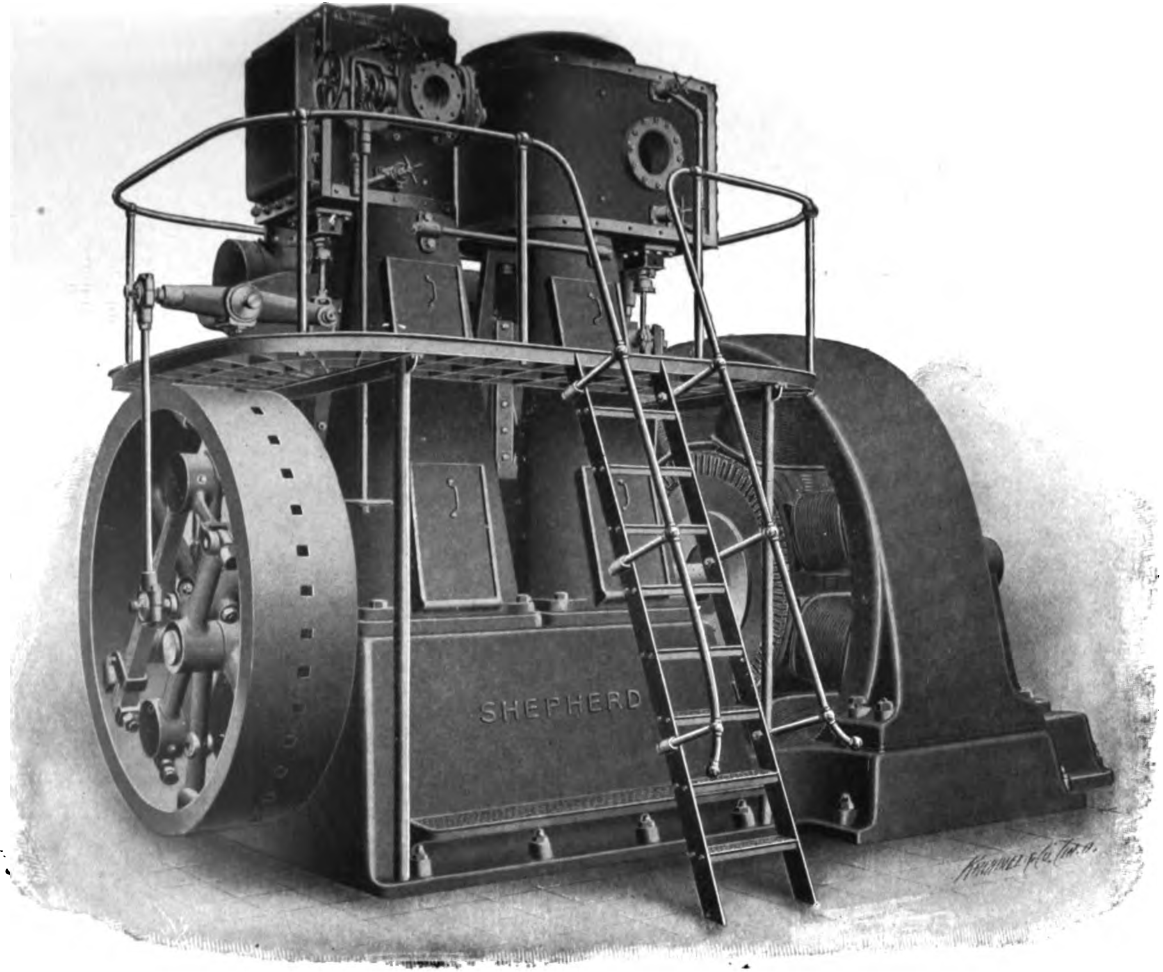


Fig. 13.



VERTICAL CROSS-COMPOUND ENGINE DIRECT-CONNECTED TO 400 K.W. DYNAMO.

Shepherd Engineering Company.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

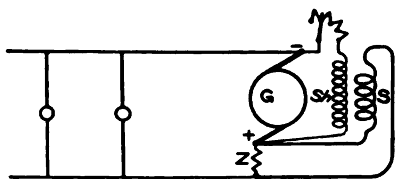


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

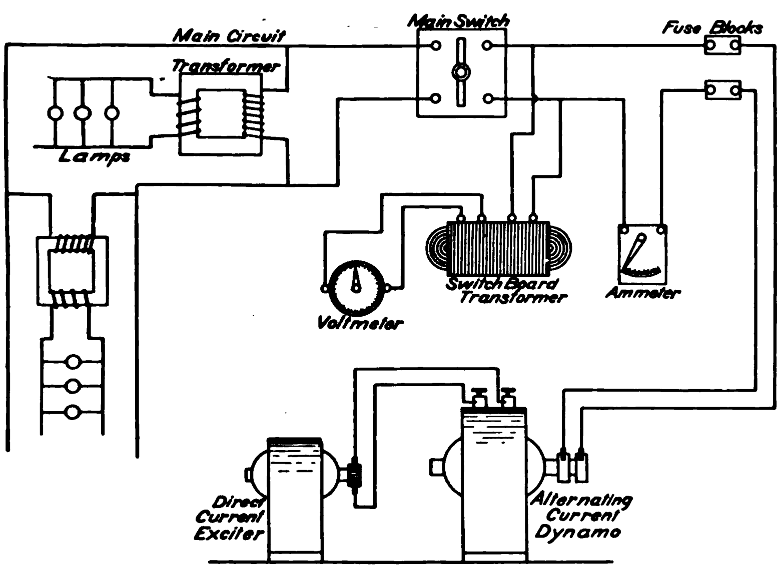


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the

different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16*a* and 16*b*, the former being known as the "Y" system or "Star"

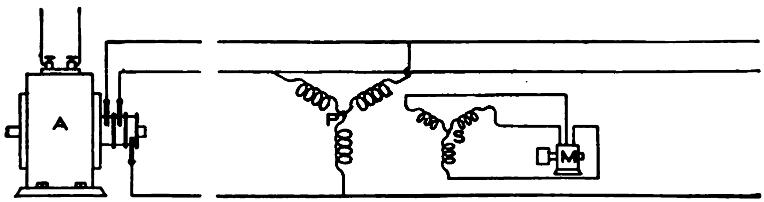


Fig. 16*a*.

system, and the latter as the "Delta" (Δ) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16*c*.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually

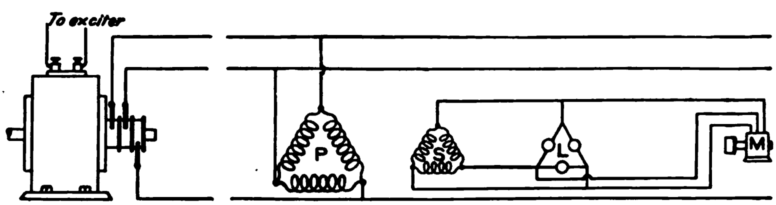


Fig. 16*b*.

designed to be right-handed, but the manufacturer will make them left handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

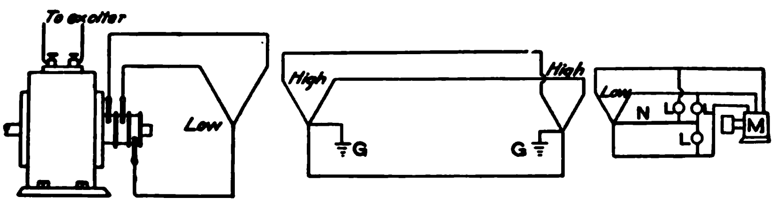


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the

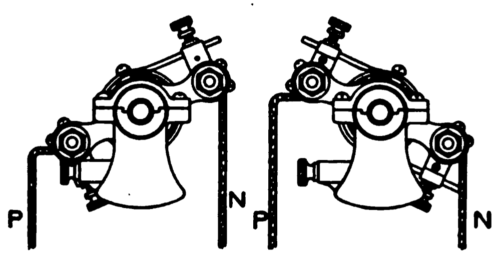


Fig. 17.

commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are per-

pendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to

speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion, The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the − (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the cir-

cuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

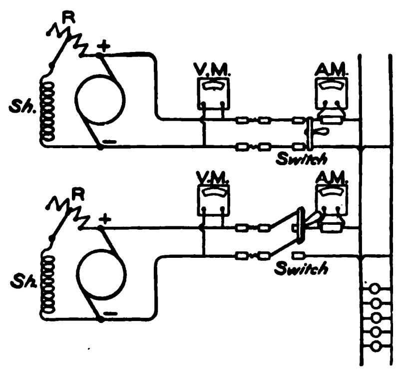


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two – brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

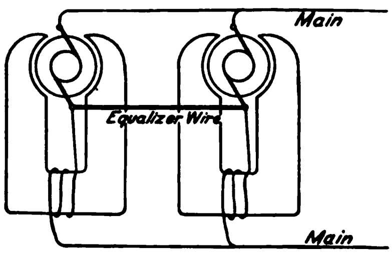


Fig. 19.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so

sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their volt-

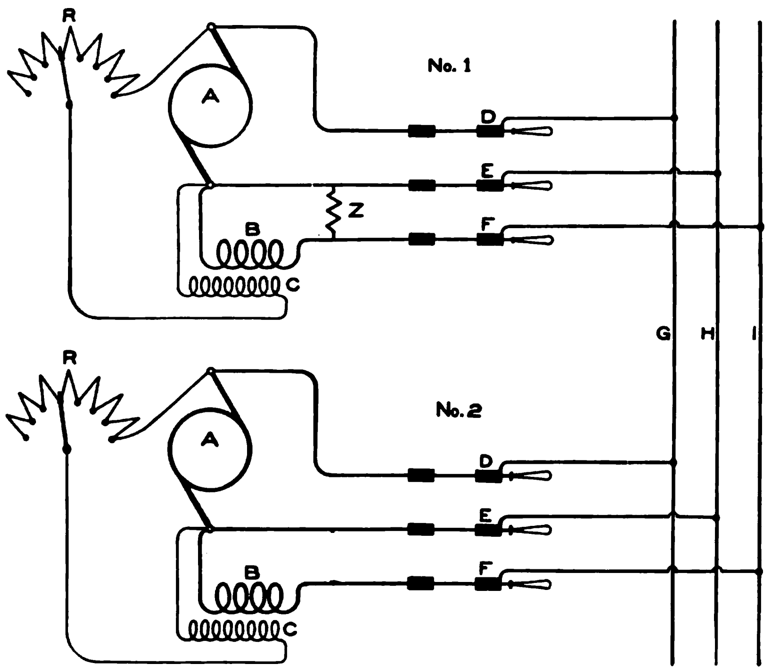


Fig. 20.

ages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel,

several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N

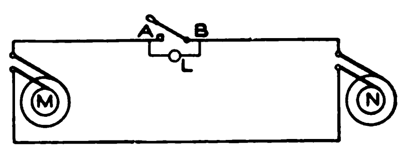


Fig. 21

to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches snychronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

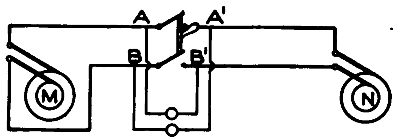


Fig. 22.

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A′ and the same point; likewise B and B′ have the same relative potential values. Hence a lamp connected between A and B′ would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B′ are of the same relative potential value, and B and A′ are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

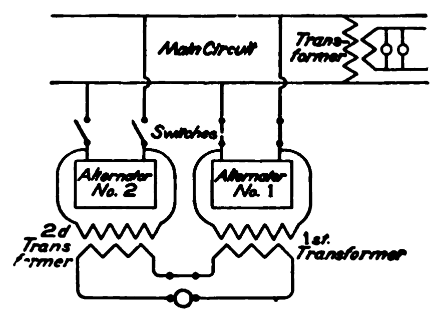


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduc-

tion of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

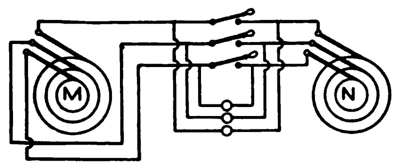


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

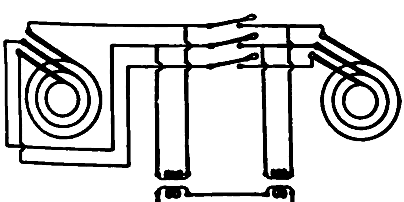


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very

successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some

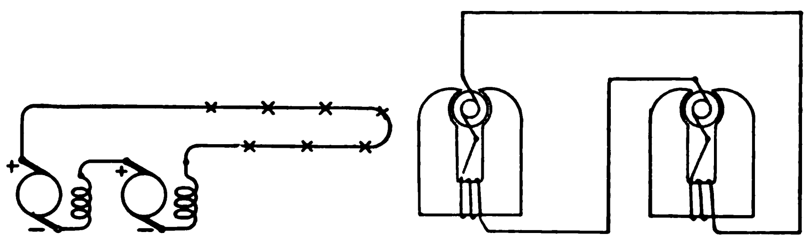


Fig. 26..

form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only

by the armature of the other machine; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

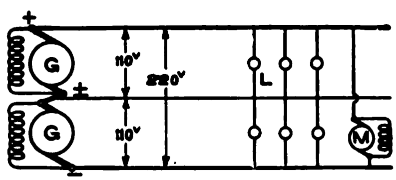


Fig. 27*a*.

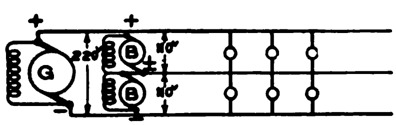


Fig. 27*b*.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual

starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

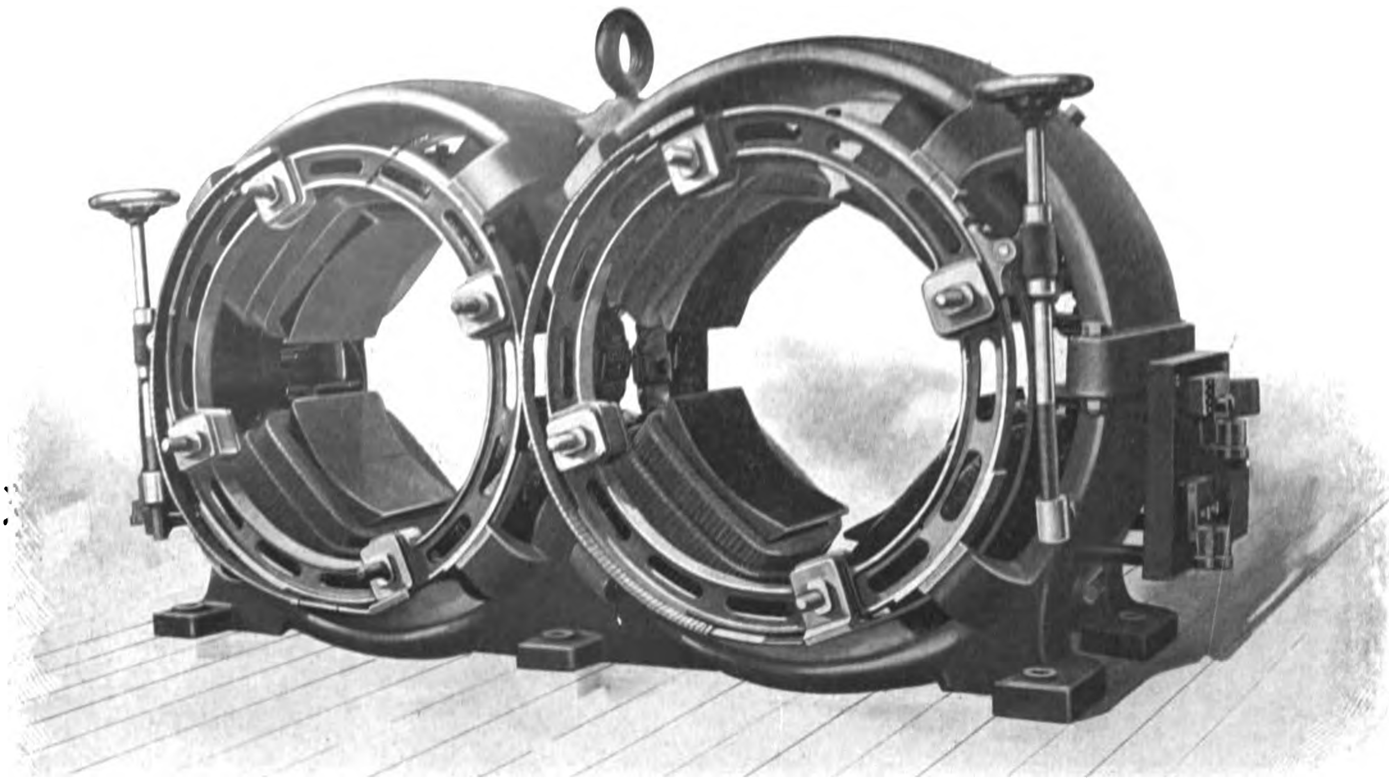
CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the posi-



FIELD FRAME 200 K.W., D.C. GENERATOR.

De Laval Steam Turbine Co.

tion shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils *a*, *a*, *a* are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;"

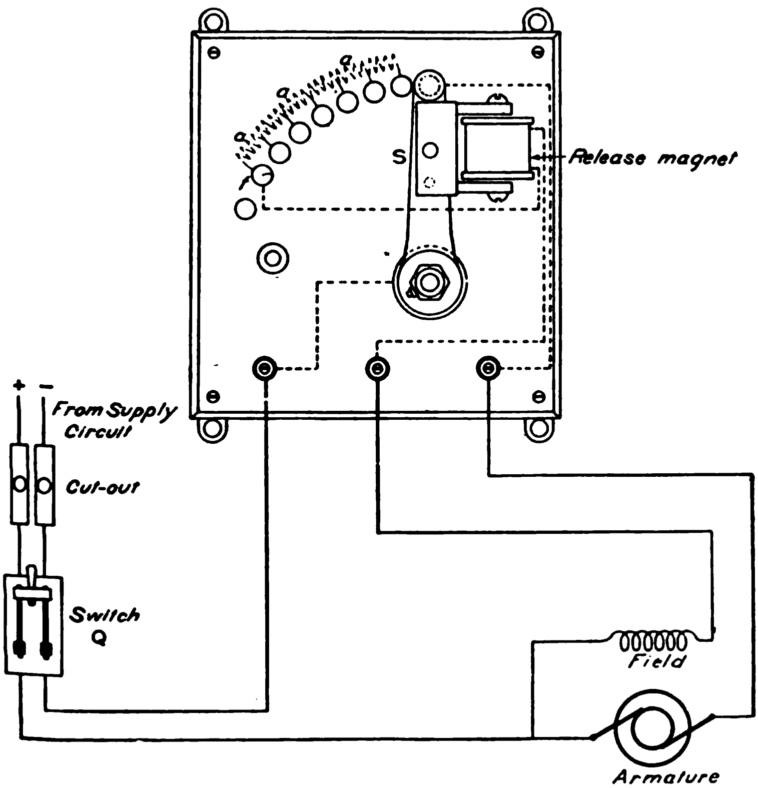


Fig. 28.

but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying

the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

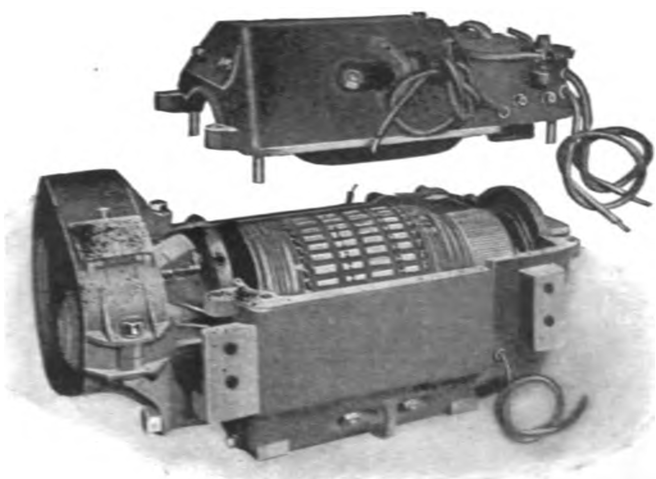


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists

are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at con-

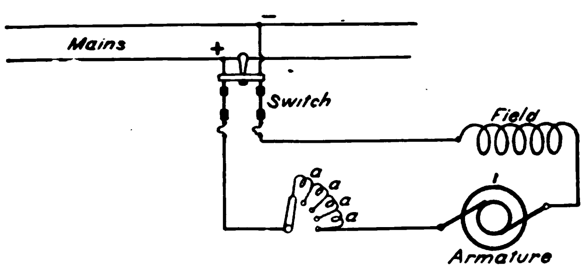


Fig. 30.

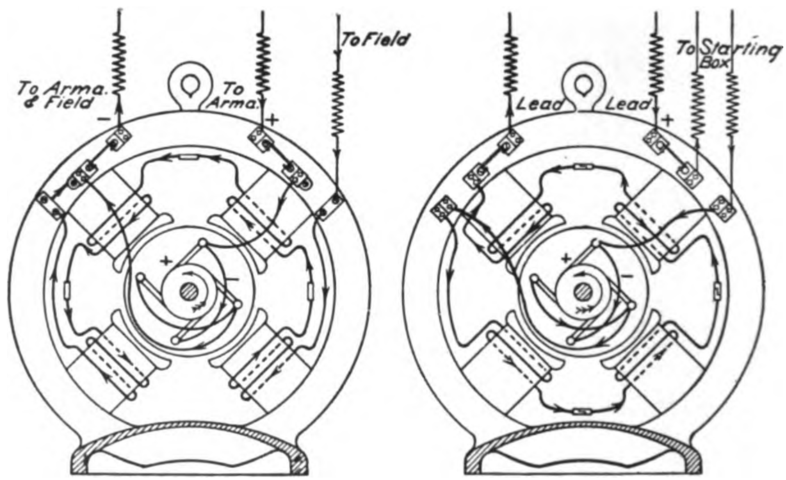
stant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated,

however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has



Shunt-wound Motor. Series-wound Motor.

Fig. 31.

the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other

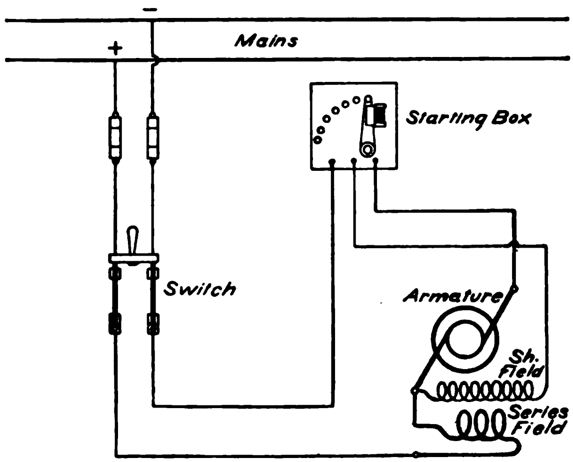


Fig. 32.

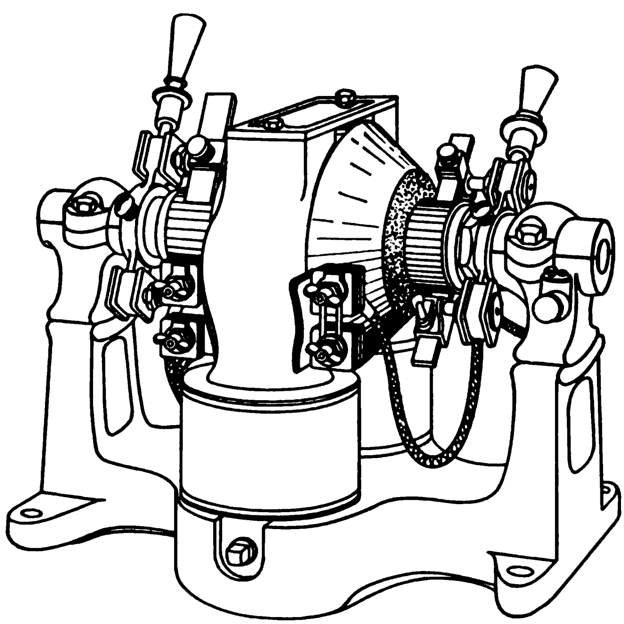


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing

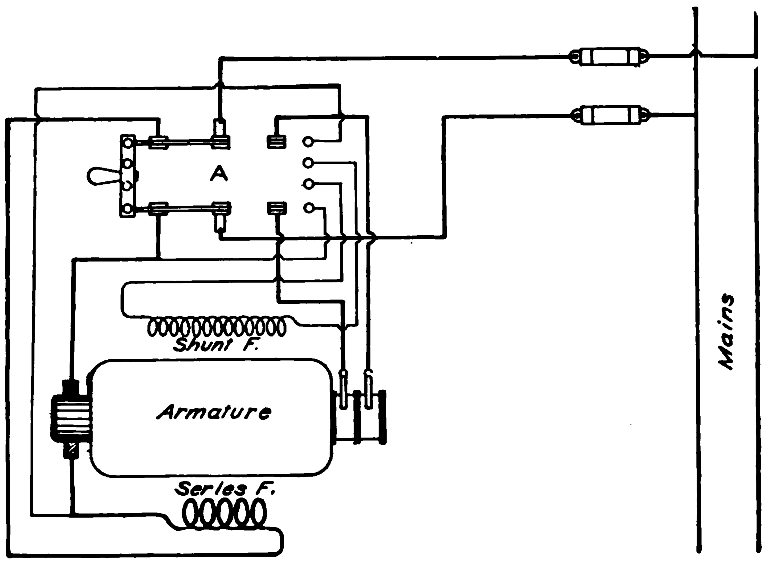


Fig. 34.

direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor.* The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to

be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor

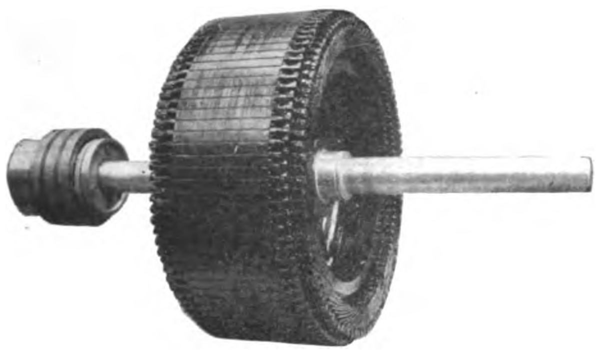


Fig. 36.

windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush

of current is excessive and likely to disturb the system ; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer

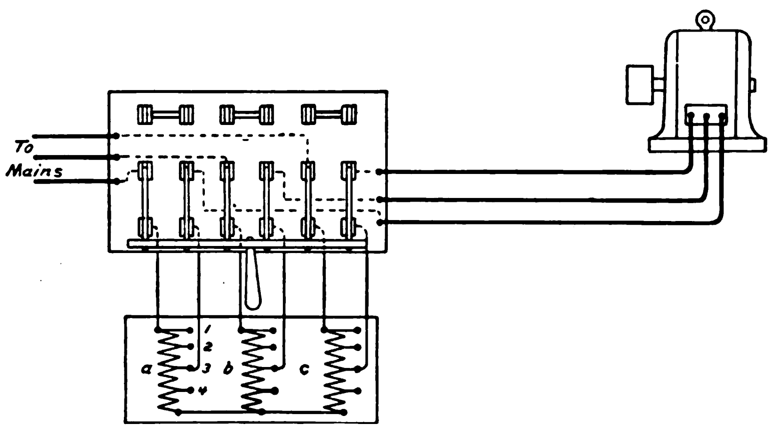


Fig. 37.

having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

* This inrush of current is frequently three times the rated load current.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.
b. Cutting down the voltage applied to the stator, as just described.

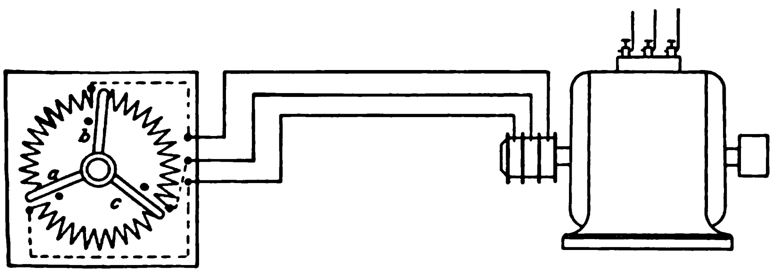


Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle

closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

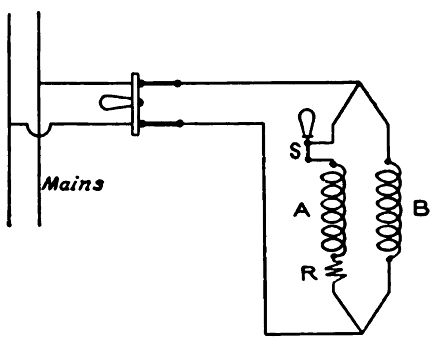


Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit*, and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit*, as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

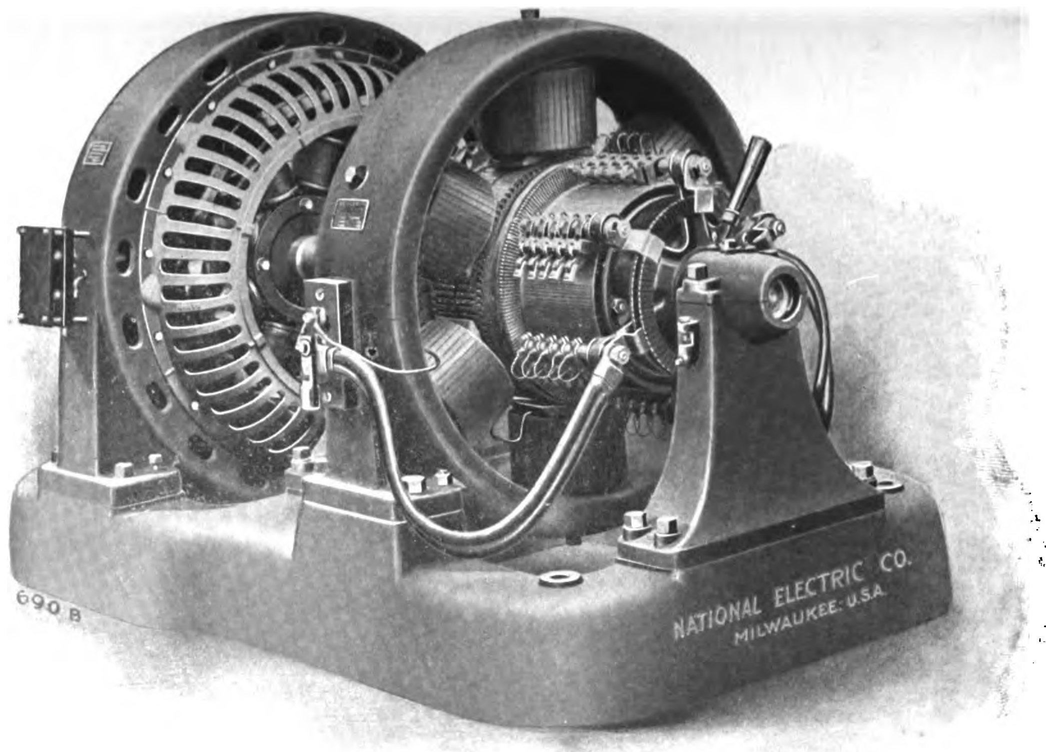
Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.



"NATIONAL" MOTOR-EXCITER SET.

50 K.W. 900 R.P.M.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

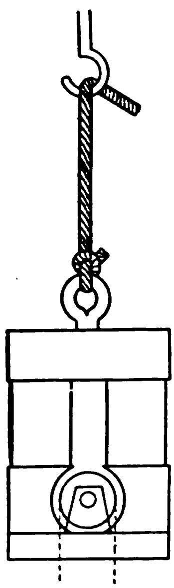


Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

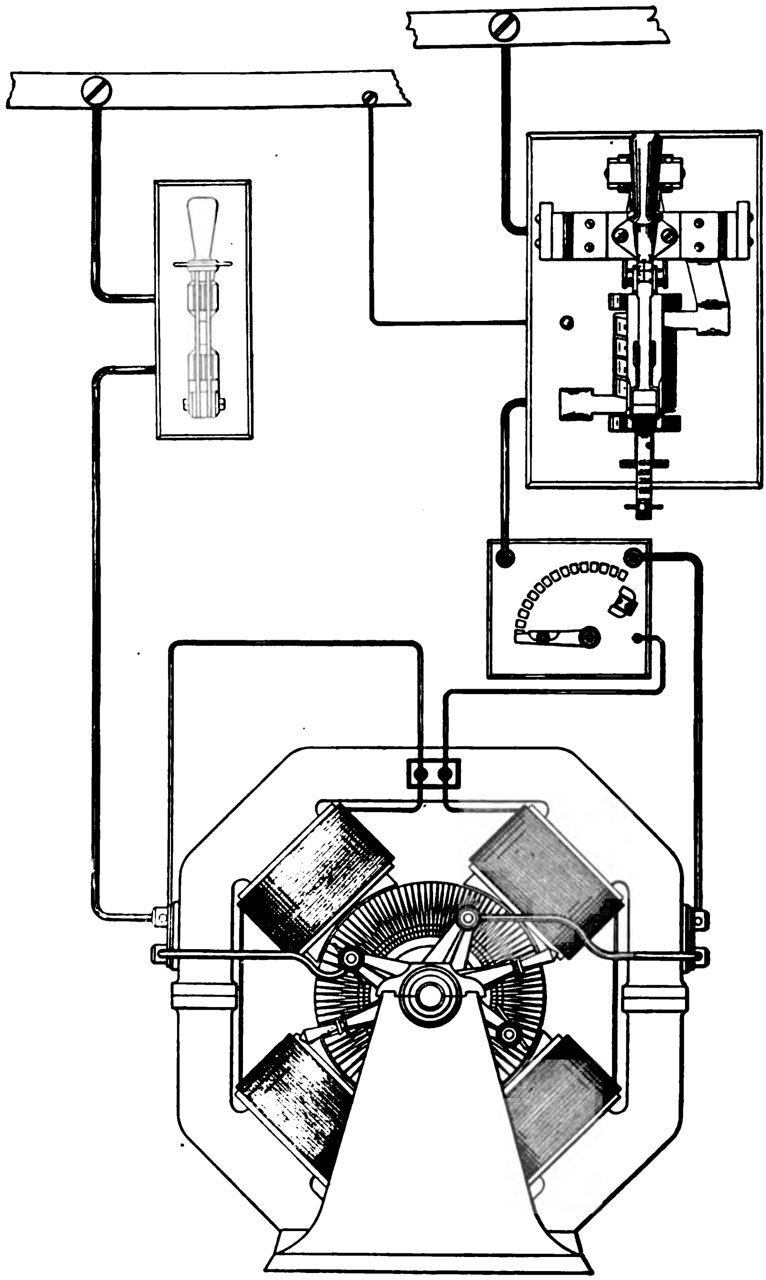
The rise of temperature is:

$$\theta = (238.1 + t)\left(\frac{(R_{t+\theta}}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_{t} + {\theta})$ the final resistance at a temperature elevation of $\theta°$ C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\mp \frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.



WIRING DIAGRAM.

Connections of Single Pole Overload and no Voltage I-T-E Circuit Breaker.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the

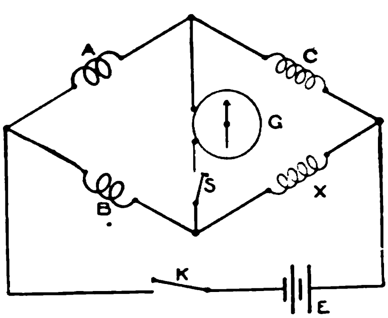


Fig. 41.

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected

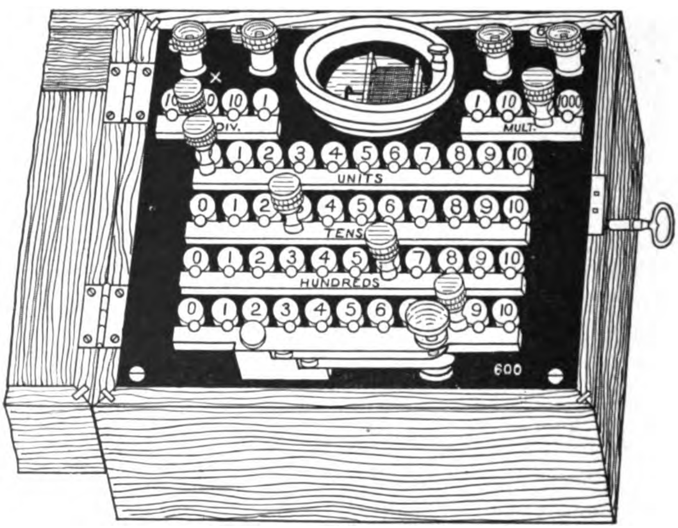


Fig. 42.

in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or Fall-of-Potential) Method is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series,

as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a

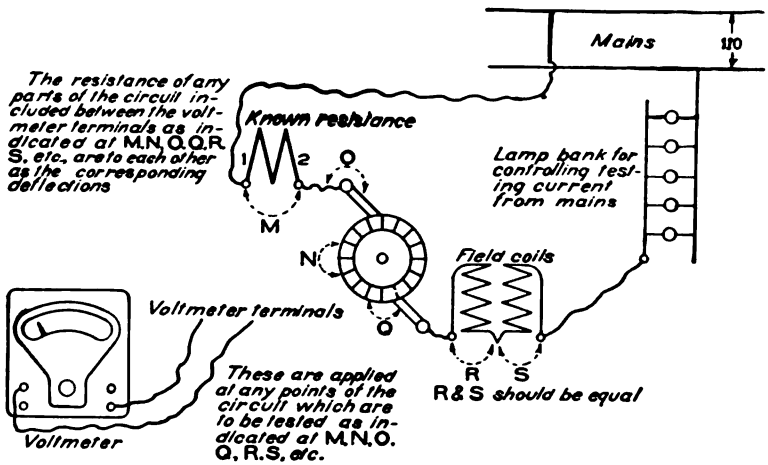


Fig. 43.

known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current

of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be

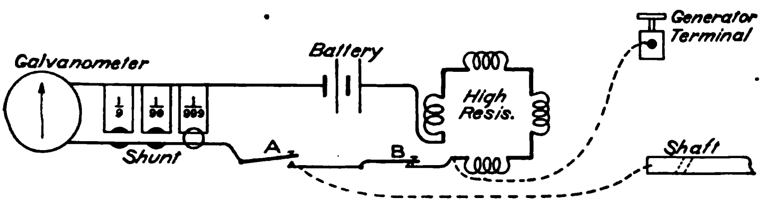


Fig. 44.

indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44 The galvanometer should be shunted with the $\frac{1}{999}$ coil of the

shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has

about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

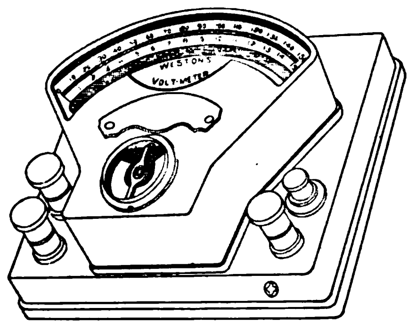


Fig. 45.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and d the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115\, R}{X + R},$$

in which X is the insulation resistance (1 megohm, $\frac{1}{2}$ megohm, etc.), and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms—which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms; and if it does not ring, it shows that the insulation is more than

that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

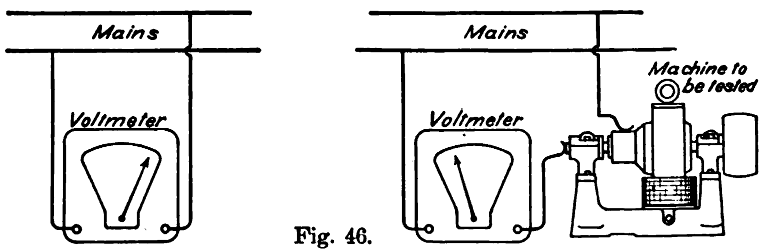


Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

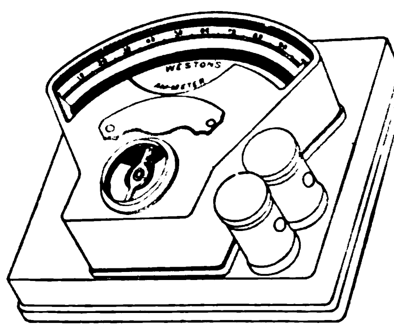
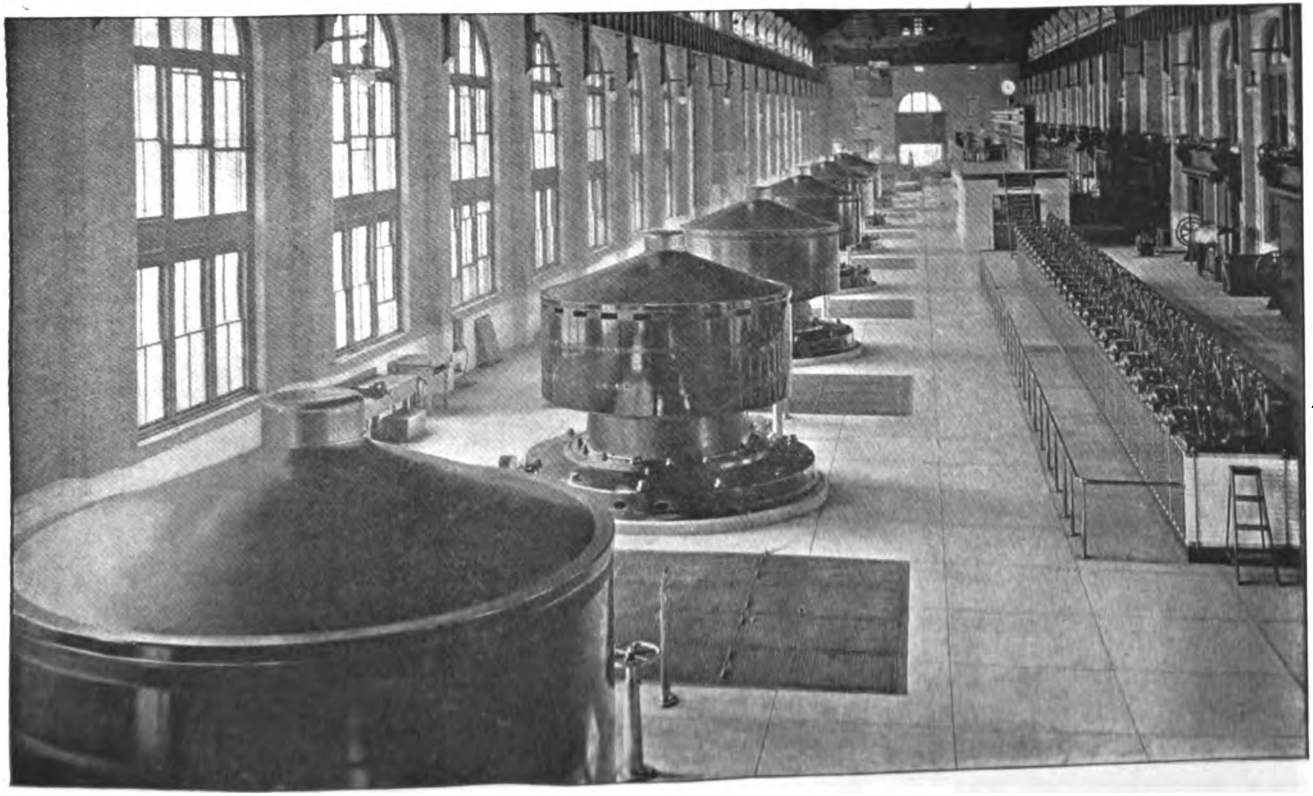


Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter tem-

* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.



POWER HOUSE NO. 2, NIAGARA FALLS POWER CO.

Eleven Generators of 5000 H. P. Each.

porarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for

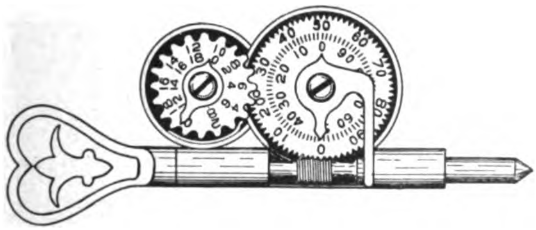


Fig. 48.

example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or

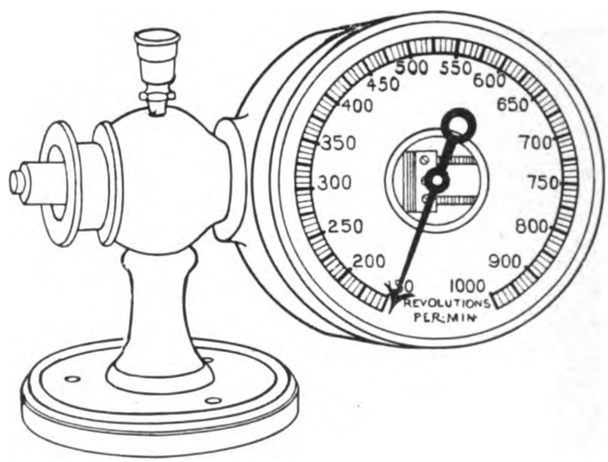


Fig. 49.

light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and

note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, this belt should pass around the pulley

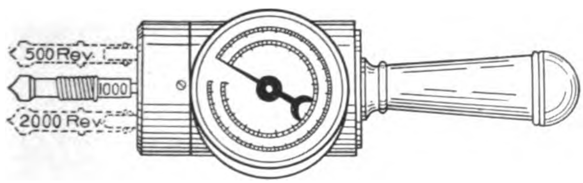


Fig. 50.

of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by

known weights, or more conveniently by a spring balance P. If desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times \text{S}},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

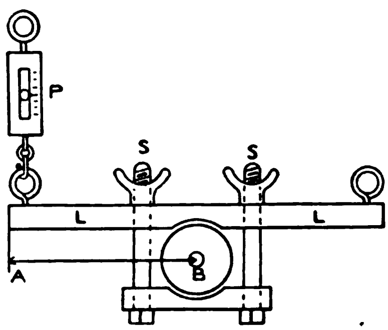


Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the

*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33,000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power.*

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a

small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since $.90 \times .90 = .81$. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

* When alternating-current machinery is being tested use wattmeters

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very

large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows :

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula : Watts $= \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the "I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating-or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows :

Useful power developed	about	92	per cent.
Used in magnetizing field	about	1 to 2	"
Loss in armature resistance (I^2R)	"	1 to 2	"
Friction of bearings	about	2	"
Friction of brushes	"	½	"
Friction of air	"	½	"
Hysteresis in armature core	"	1½	"
Foucault currents in armature core	"	1½	"

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A

wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

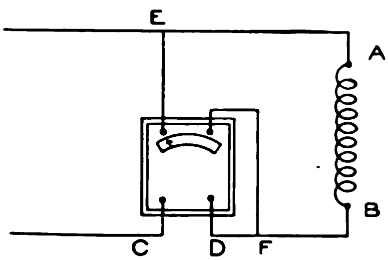


Fig. 52.

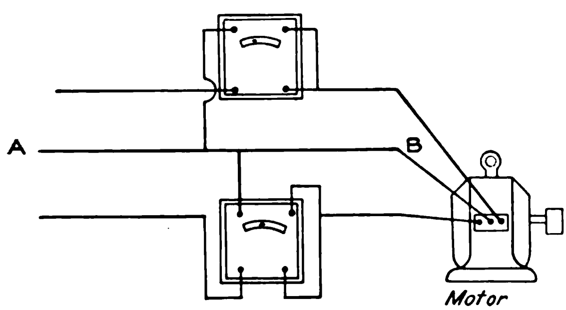


Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a watt-

meter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53, * where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the out-*

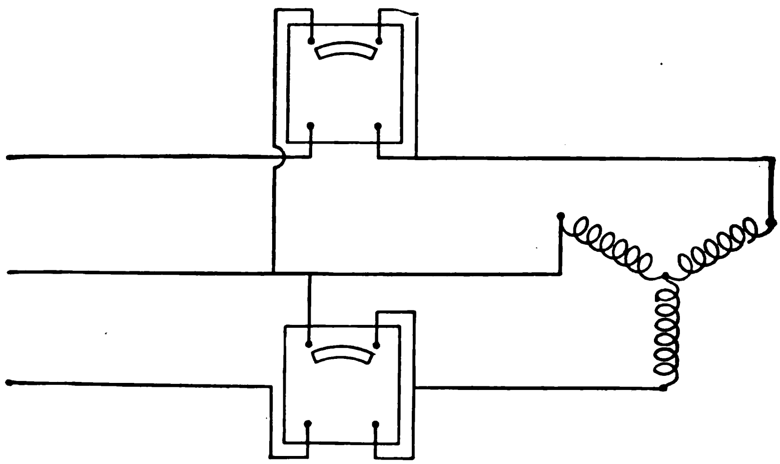


Fig. 54*a*.

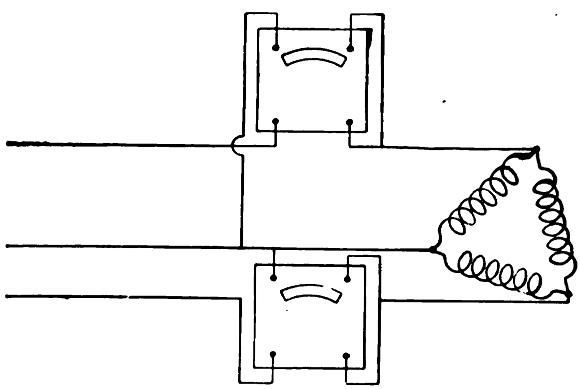


Fig. 54*b*.

side mains; and the power supplied is equal to the sum of the two wattmeter readings.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as

* This form of connection is possible only when the generator has two independent windings, ... for each phase.

shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

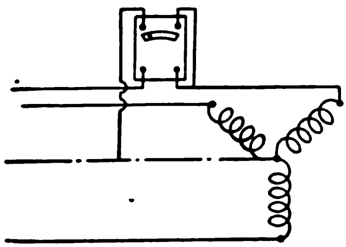


Fig. 55.

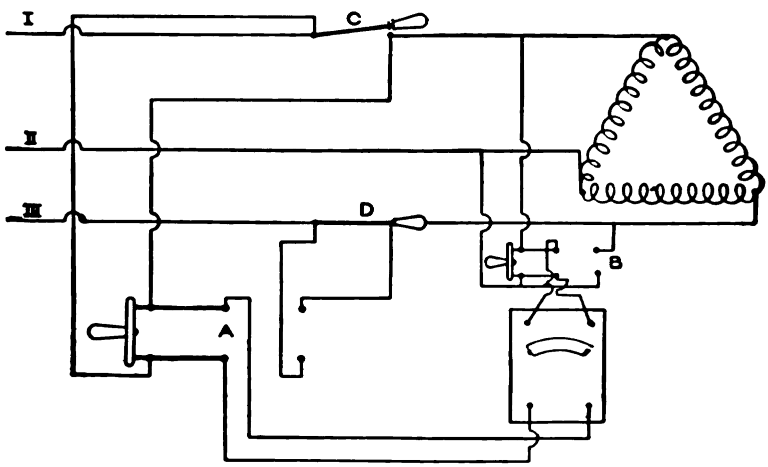


Fig. 56.

To measure the power of a balanced 4-wire 3 phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.:*

- **I. Sparking at Commutator.**
- **II. Heating of Commutator and Brushes.**
- **III. Heating of Armature.**
- **IV. Heating of Field Magnets.**
- **V. Heating of Bearings.**
- **VI. Noisy Operation.**
- **VII. Speed not right.**
- **VIII. Motor stops or fails to start.**
- **IX. Dynamo fails to generate.**
- **X. Voltage not right.**

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce

two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. **Armature carrying too much current,** due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case

of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

CAUSE 2, **Brushes not set at the neutral point.**

SYMPTOM. Sparking varied by shifting the brushes with rocker-arm.

REMEDY. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by

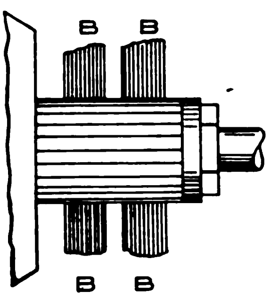


Fig. 57.

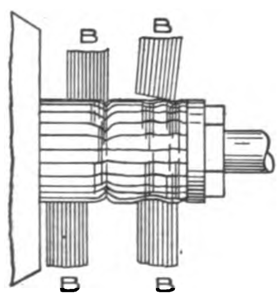


Fig. 58.

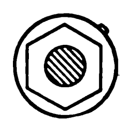


Fig. 59.

simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate, and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

CAUSE 3. **Commutator rough, eccentric, or has one or more "high bars"** projecting beyond the others, or one or more

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

SYMPTOM. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

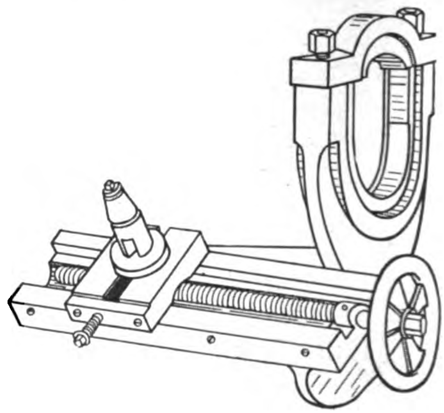
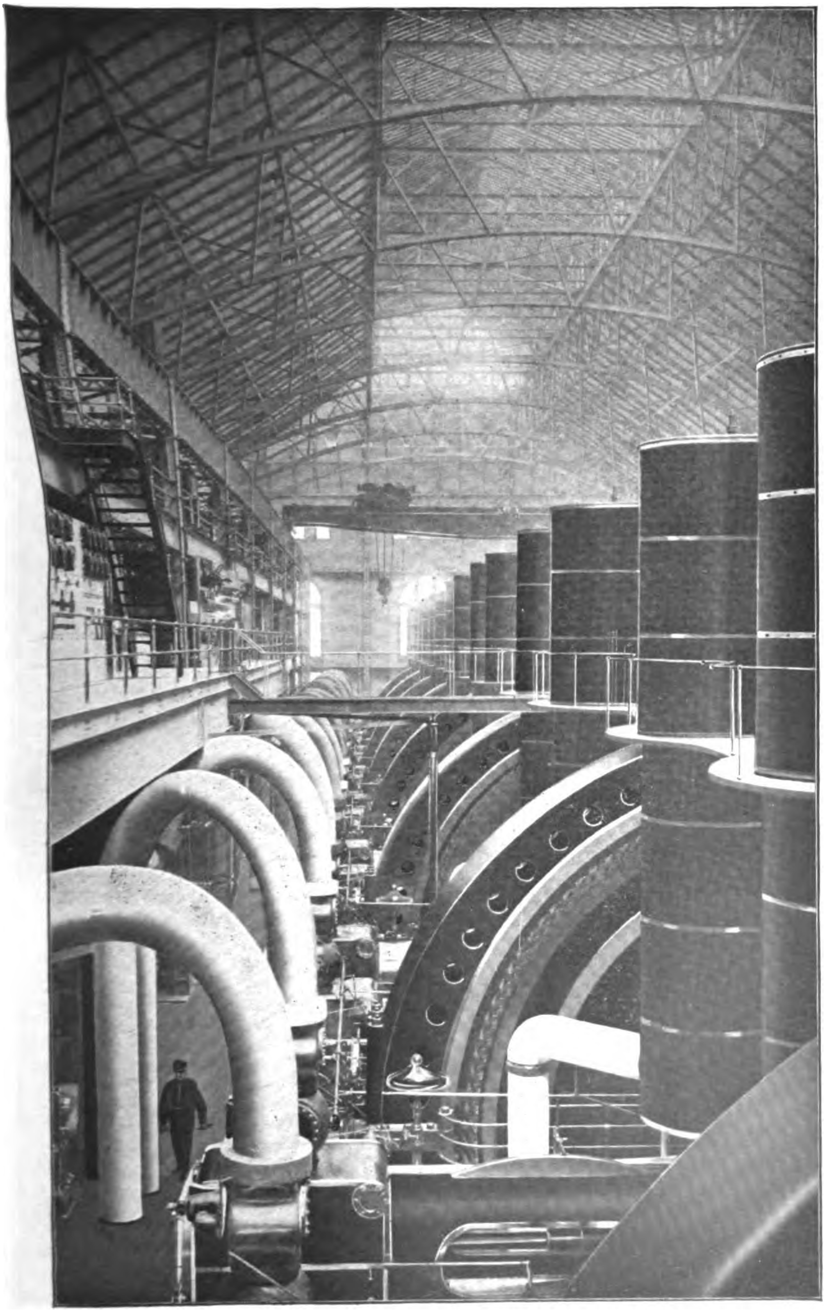


Fig. 60.

REMEDY. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished



MANHATTAN 74th ST. POWER STATION, NEW YORK.

Showing Carey's Carbonate of Magnesia Pipe Coverings. Steam Connections.

by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

CAUSE 4. **Brushes make poor contact with commutator.**

SYMPTOM. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

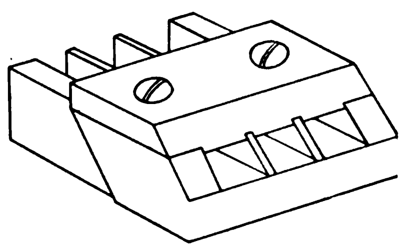


Fig. 61.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

REMEDY. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

CAUSE 5. **Short-circuited or reversed coil or coils in armature.**

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. **Broken circuit in armature.**

SYMPTOM. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in

this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

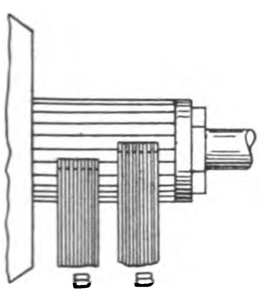


Fig. 62.

Cause 7. **Ground in Armature.**

Symptom. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

Remedy. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, wiil reduce the voltage of the former or raise the speed of the latter with increase of load.

* NOTE. If the motor is not loaded, it will race.

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. **Vibration of Machine.**

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. **Flying break in armature conductor.**

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes, when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by

feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

CAUSE 1. **Heat spread from another part of machine.**

SYMPTOM. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

REMEDY. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

Symptom. **Brushes hotter than other parts.**

Remedy. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

Cause 1. **Excessive current in armature coils.**

Symptom and Remedy the same as in case of "Sparking," Cause 1.

Cause 2. **Short-circuited armature coils.**

Symptom and Remedy the same as in case of "Sparking;" Cause 5. See also Cause 7.

Cause 3. **Moisture in armature coils.**

Symptom. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature ; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

Remedy. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

Cause 4. **Foucault currents in armature core.**

Symptom. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

Note. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

REMEDY. Armature core should be laminated more perfectly, which is a matter of first construction.

CAUSE 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

SYMPTOM. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

REMEDY. Reconnect the coil to agree with the others.

CAUSE 6. **Heat conveyed from other parts.**

SYMPTOM. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

REMEDY. See Heating of Bearings, Field and Commutator.

CAUSE 7. **Flying cross in armature conductor.**

SYMPTOM and REMEDY similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

CAUSE 1. **Excessive current in field circuit.**

SYMPTOM. Field coils too hot to keep the hand on. Their temperature more than 50 C above that of room by resistance test or by thermometer.

REMEDY. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the

pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

CAUSE 2. **Foucault currents in pole pieces or field cores.**

SYMPTOM. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

REMEDY. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

CAUSE 3. **Moisture in field coils.**

SYMPTOM. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

REMEDY. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is

very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

Cause 1. **Lack of oil.**

Symptom. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

Remedy. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

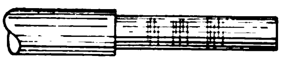


Fig. 63.

Cause 2. **Grit or other foreign matter in bearings.**

Symptom. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

Remedy. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

Cause 3. **Shaft rough or cut.** (Fig. 63.)

Symptom. Shaft will show grooves or roughness, and will probably revolve stiffly.

Remedy. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

Cause 4. **Shaft and bearing fit too tight.**

Symptom. Shaft hard to revolve by hand.

Remedy. Turn or file down shaft in lathe, or scrape or ream out bearings.

Cause 5. **Shaft "sprung" or bent.**

Symptom. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

Remedy. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

CAUSE 6. **Bearings out of line.**

SYMPTOM. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

REMEDY. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

CAUSE 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

SYMPTOM. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

REMEDY. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

CAUSE 8. **Too great a load or strain on the belt.**

SYMPTOM. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

REMEDY. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

CAUSE 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

SYMPTOM. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

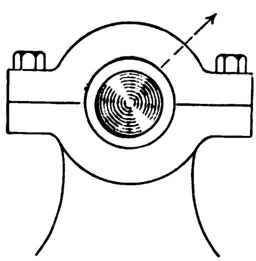


Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

CAUSE 10. **Bearing heated by hot pulley, commutator, or armature.**

SYMPTOM. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

REMEDY. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

CAUSE 1. **Vibration due to armature or pulley being out of balance.**

SYMPTOM. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

REMEDY. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

CAUSE 2. **Armature strikes or rubs against pole pieces.**

SYMPTOM. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

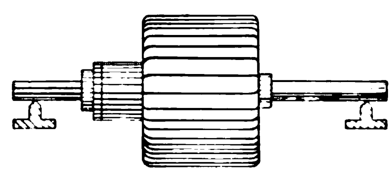


Fig. 65.

REMEDY. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

CAUSE 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

SYMPTOM. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

REMEDY. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

CAUSE 4. **Rattling due to looseness of screws or other parts.**

SYMPTOM. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

REMEDY. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

CAUSE 5. **Singing or hissing of brushes.** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

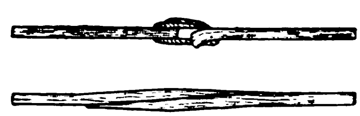
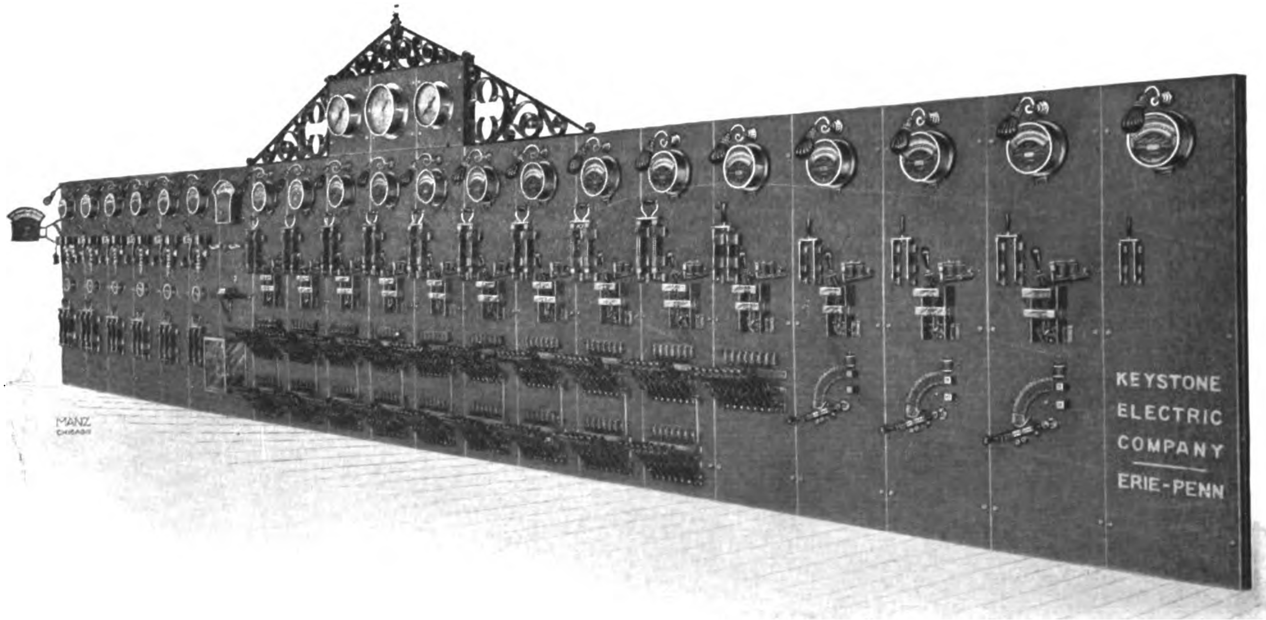


Fig. 66.

SYMPTOM. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

REMEDY. Apply a *very little* oil or vaseline to the commu-



SWITCHBOARD OF THE WHITEHALL PORTLAND CEMENT CO.

Built and Installed by the Keystone Electric Co.

tator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. **Slipping of belt on pulley due to overload.**

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion ; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. **Humming of armature-core teeth as they pass pole-pieces.**

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. **Humming due to alternating or pulsating current.**

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

REMEDY. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

CAUSE 1. **Overload.** (See "Sparking," Cause 1.)

SYMPTOM. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

REMEDY. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

CAUSE 2. **Short circuit or ground in armature.**

SYMPTOM and REMEDY the same as in case of "Heating of Armature, Cause 2 and Cause 6.

CAUSE 3. **Armature strikes pole pieces.**

SYMPTOM and REMEDY the same as in case of "Noise," Cause 2.

CAUSE 4. **Shaft does not revolve freely in the bearings.**

SYMPTOM and REMEDY the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

CAUSE 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as,

for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ")

CAUSE 6. **Too high or too low voltage on the circuit.**

SYMPTOM. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

REMEDY. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

CAUSE 7. **Motor too lightly loaded.**

SYMPTOM. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

REMEDY. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

CAUSE 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

SYMPTOM. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

REMEDY. Turn off switch instantly, reduce or take off the

load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator; (*d*) switch open; (*e*) circuit supplying motor open; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric

bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south*

pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. **Reversed connections or reverse direction of rotation.**

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both.* (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. **Short circuit in the machine or external circuit.**

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. **Field-coils opposed to each other.**

SYMPTOM. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet,

showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also " Motor Stops," etc., Cause 3.)

A break, poor-contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

CAUSE 6. **Brushes not in proper position.**

SYMPTOM. The magnetism and current are increased by shifting the brushes.

REMEDY. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 130°; and 16-pole, either 22½°, 67½°, 112°, or 157½°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

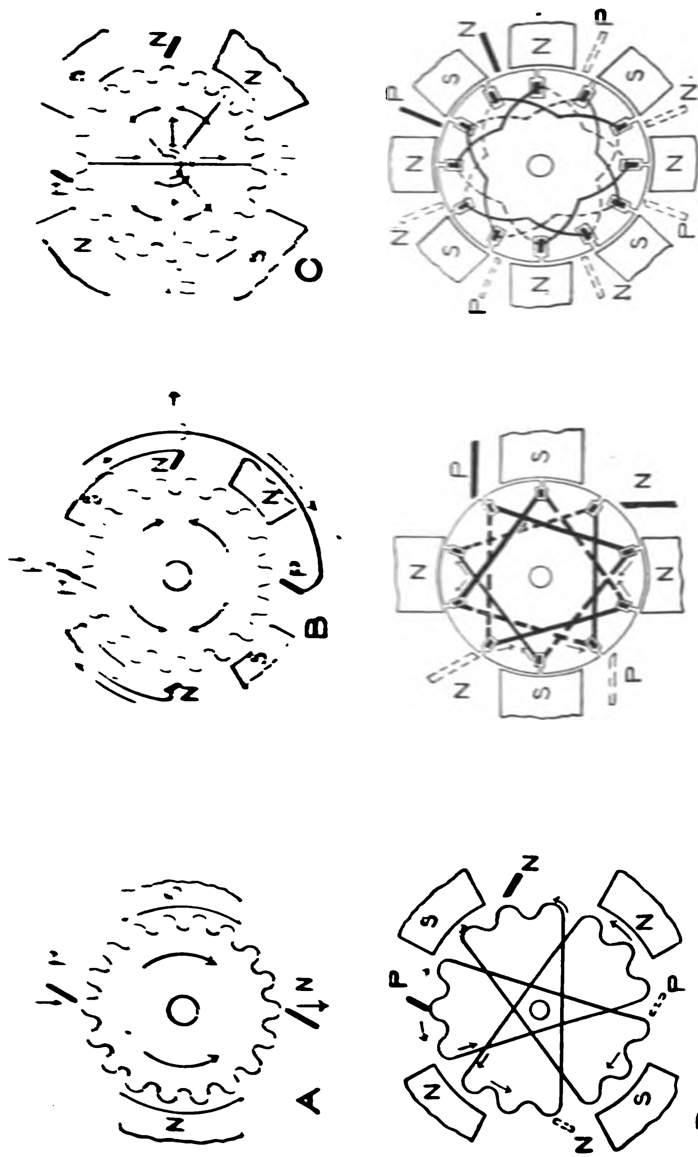


Fig. 67.

A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.

D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

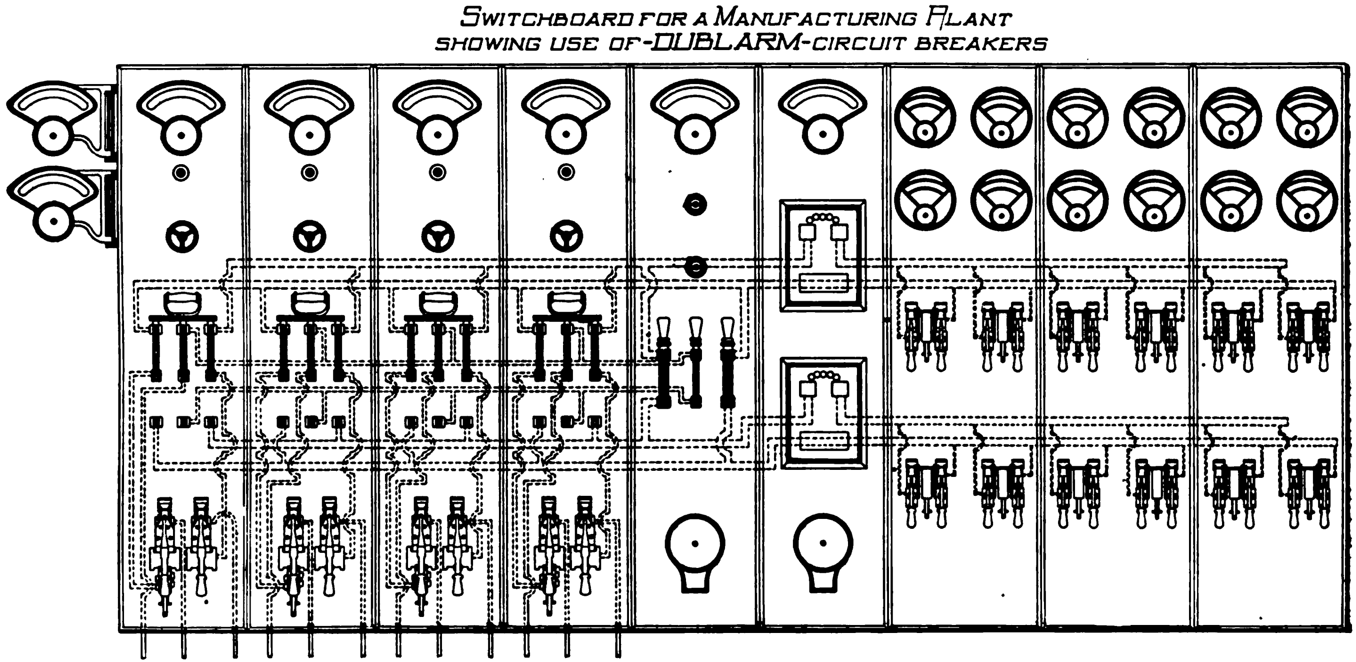
CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**
REMEDY. Decrease resistance of series field shunt.
(**See** Compound-wound Dynamos, page 25, Part I.)



SWITCHBOARD.

The Cutter Company.

ELECTRIC WIRING.

INSTALLING THE DYNAMO.

Dynamos should be located in a dry place so situated that the surrounding atmosphere is cool. If the surrounding air is warm, it reduces the safe carrying capacity of the machine and is likely to allow such temperature to rise in the machine itself as to burn out either armature or field, or both. A dynamo should not be installed where any hazardous process is carried on, nor where it would be exposed to inflammable gases or flying combustible materials, as the liability to occasional sparks from the commutator or brushes might cause serious explosions.

Wherever it is possible, dynamos should be raised or insulated above the surrounding floor, on wooden base frames, which should be kept filled to prevent the absorption of moisture, and also kept clean and dry. When it is impracticable to insulate a dynamo on account of its great weight, or for any other reason, the Inspection Department of the Board of Fire Underwriters having jurisdiction may, in writing, permit the omission of the wooden base frame, in which case the frame should be permanently and effectively grounded. When a frame is grounded, the insulation of the entire system depends upon the insulation of the dynamo conductors from the frame, and if this breaks down the system is grounded and should be remedied at once.

Grounding Dynamo Frames can be effectually done by firmly attaching a wire to the frame and to any main water pipe inside the building. The wire should be securely fastened to the pipe by screwing a brass plug into the pipe and soldering the wire to this plug. When the dynamo is direct driven, an excellent ground is obtained through the engine coupling and the piping of the engine and boiler.

Wherever high-potential machines have their frames grounded, a small board walk should be built around them and raised above the floor, or porcelain on glass insulators, in order that the

dynamo tender may be protected from a shock when adjusting brushes or working about the machine.

Sufficient space should be left on all sides of the dynamo and especially at the commutator end, so that there may be ample room for removing armatures, commutators, or any other parts at any time.

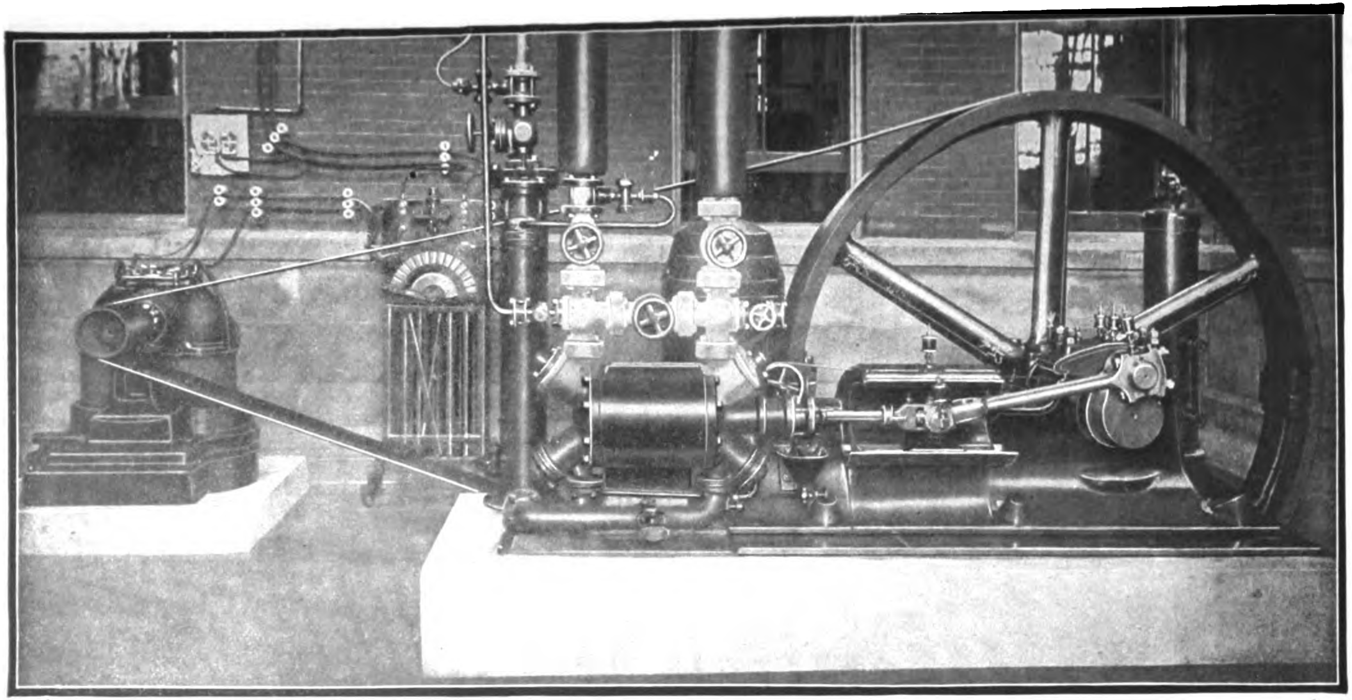
Circuit Breakers and Fuses. Every constant-potential generator should be protected from excessive current by a safety fuse or equivalent device of approved design, in each wire lead, such as a circuit breaker. The latter is preferable, on account of its being immeasurably more accurate and convenient for resetting. Such devices should be placed on or as near as possible to the dynamo. When the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

The best practice is to place the fuses on the dynamo itself, and the circuit breakers on the switchboard.

Waterproof Covers should be provided for every dynamo and placed over each machine as soon as it is shut down. Negligence in this matter has caused many an armature and field coil to burn out, as only a few drops of water are necessary to cause a short circuit as soon as the machine is started up again, which might do many dollars' worth of damage, to say nothing of the inconvenience caused by shutting off light or power when it is most needed, and for an indefinite length of time.

Name-Plates. Every dynamo should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute. This will show exactly what the machine was designed for, and how it should be run.

Wiring from Dynamos to switchboards should be in plain sight or readily accessible, and should be supported entirely upon non-combustible insulators, such as glass or porcelain; in no case should any wire come in contact with anything except these insulators, and the terminals upon the dynamos and switchboards. When it becomes necessary to run these wires through a wall or floor, the holes must be protected by some approved non-combus-



12-TON LINDE REFRIGERATING MACHINE.

Operated by an Electric Motor.

Fred W. Wolf Company.

tible insulating tube, such as glass or porcelain, and in every case the tube must be fastened so that it shall not slip or pull out. Sections of any tubing, whether armored or otherwise, that are chopped off for this purpose, should not be used. All wires for dynamos and switchboard work should be kept so far apart that there is no liability of their coming in contact with one another, and should be covered with non-inflammable insulating material sufficient to prevent accidental contact, except that bus bars may be made of bare metal so that additional circuits can be readily attached. Wires must have ample carrying capacity, so as not to heat with the maximum current likely to flow through them under natural conditions. (See "Capacity of Wires Table," page 37.) So much trouble in past years has arisen from faulty construction of switchboards, and the apparatus placed upon them, that strict requirements have been necessarily adopted by engineers as well as insurance inspectors, and the following suggestions are recommended by the latter:

The Switchboard should be so placed as to reduce to a minimum the danger cf communicating fire to adjacent combustible material, and, like the dynamo, should be erected in a dry place and kept free from moisture. It is necessary that it should be accessible from all sides when the wiring is done on the back of the board, but it may be placed against a brick or stone wall when all wiring is on the face.

The board should be constructed wholly of non-combustible material, but when this is impossible a hard-wood board made in skeleton form, and well filled to prevent absorption of moisture, is considered safe. Every instrument, switch or apparatus of any kind placed upon the switchboard should have its own non-combustible insulating base. This is required of every piece of apparatus connected in any way with any circuit. If it is found impossible to place the resistance box or regulator (which should, in every case, be made entirely of non-combustible material) upon the switchboard, it must be placed at least one foot from combustible material or separated therefrom by a non-inflammable, non-absorptive insulating material. A slate slab is preferable. Special attention is called to the fact that switchboards should not

be built down to the floor, nor up to the ceiling, but a space of at least ten or twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board, in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent space being used for storage of rubbish and oily waste.

Lightning Arresters should be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines. They should be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switchboard. In all cases, kinks, coils and sharp bends in the wires between the arresters and the outdoor lines should be avoided as far as possible. Arresters should be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, and running as nearly as possible in a straight line from the arresters to the earth connection.

Ground wires for lightning arresters should not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

Unless a good, damp ground is used in connection with all lightning arresters, they are practically useless. Ground connections should be of the most approved construction, and should be made where permanently damp earth can be conveniently reached. For a bank of arresters such as is commonly found in a power house, the following instructions will be found valuable: First, dig a hole six feet square directly under the arresters, until permanently damp earth has been reached; second, cover the bot-

tom of this hole with two feet of crushed coke or charcoal (about pea size); third, over this lay twenty-five square feet of No. 16 copper plate; fourth, solder at least two ground wires, which should not be smaller than No. 6, securely across the entire surface of the ground plate; fifth, now cover the ground plate with two feet of crushed coke or charcoal; sixth, fill in the hole with earth, using running water to settle.

All lightning arresters should be mounted on non-combustible bases and be so constructed as not to maintain an arc after the discharge has passed; they should have no moving parts.

Testing of Insulation Resistance. All circuits except those permanently grounded should be provided with reliable ground detectors. Detectors which indicate continuously and give an instant and permanent indication of a ground are preferable. Ground wires from detectors should not be attached to gas pipes within the building.

Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day.

Data obtained from all tests should be preserved for examination.

Storage or Secondary Batteries should be installed with as much care as dynamos, and in wiring to and from them the same precautions and rules should be adopted for safety and the prevention of leaks. The room in which they are placed should be kept not only dry, but exceptionally well aired, to carry off all fumes which are bound to arise. The insulators for the support of the secondary batteries should be glass or porcelain, as filled wood alone would not be approved.

Care of Dynamos. A few suggestions as to the care of the dynamo, as well as its installation, may be of value; and one of the important points under this head is that the driving power should have characteristics of steadiness and regularity of speed, and should always be sufficient to drive the dynamo with its full load, besides doing the other work which it may be called upon to sustain. Unsatisfactory results are always obtained by attempting to run a dynamo on an overloaded engine.

Wooden bed-plates are supplied, when ordered, for all dynamos, except in the largest and direct-connected machines.

Most machines are fitted with a ratchet and screw bolt, so that they may be moved backward or forward on the bed-plate in a direction at right angles to the armature shaft. By this means the driving belt can be tightened or loosened at will, while the machine is in operation. Care should be taken in tightening the belt not to bind the bearings of the armature and force the oil from between the surfaces of the shaft and boxes. Such practice will inevitably cause heating of the bearings and consequent injury.

Machines are usually assembled, unless ordered otherwise, so that the armature revolves clock-wise when the observer faces the pulley end of the shaft. All bipolar dynamos, however, may be driven in either direction by reversing the brushes and changing field connections.

The machine is provided with a pulley of the proper size to transmit the power demanded, and a smaller one should not be substituted unless approval be obtained from the makers.

When driving from a countershaft, or when belted directly to the main shaft, a loose pulley or belt holder should be used, to admit of starting and stopping the dynamo while the shafting is running.

Belts. A thin double or heavy single belt should be used, about a half inch narrower than the face of the pulley on the dynamo. An endless belt, one without lacing, gives the greatest steadiness to the lights.

All bolts and nuts should be firmly screwed down. All nuts which form part of electrical connections should receive special attention.

The copper commutator brushes are carefully ground to fit the commutator, and they should be set in the holders so as to bear evenly upon its surface. On machines where two or more brushes are supported on one spindle, the brushes on the same side of the commutator must be set so that they touch the same segments in the same manner. The brushes on the other side of the commutator must be set to bear on the segments diametrically

opposite. When the brushes are not so set it is impossible to run the machine without sparking. A convenient method of determining the proper bearing point for the brushes is to set the toe of one brush at the line of insulation, dividing two segments of the commutator; then count the dividing lines for one-half the way around the surface, and set the other brush or brushes at the line diametrically opposite the first. Thus, on the forty-four segment commutator, after setting the tip of one brush at a line of insulation, count around twenty-three lines, setting the other brush at the twenty-third line, thus bringing the tips directly opposite each other. The angle which the brushes form with the surface of the commutator should be carefully noted, and the brushes should not be allowed to wear so as to increase or decrease this angle. Careless handling of the machine is at once indicated by the brushes being worn either to a nearly square end, or to a long taper in which the forward wires of the brush far outrun the back or inside wires. Either condition will inevitably be attended with excessive wear of both commutator and brushes.

After copper brushes are set in contact with the commutator, the armature should never be rotated backward. If it is required to turn the armature back, raise the brushes from the commutator by the thumb screw on the holder provided for that purpose, before allowing such rotation. When starting a machine, it is always better to let the brushes down upon the commutator after the machine has started, rather than before, except when carbon brushes are used.

Bearings. See that the bearings of the machine are clean and free from grit, and that the oil reservoirs are filled with a good quality of lubricating oil. The oil reservoirs should always be examined before starting, and all loose grit removed. After starting the machine, the oil should be all drawn off at the end of each day's run for the first three or four days, after which it may be assumed that any remaining grit has been carried off with the oil, and it will only be necessary to add a little fresh oil once in seven or ten days.

Starting Up a Dynamo or Motor. Fill the oil reservoirs and see that the automatic oiling rings are free to move. In the

case of dynamos fitted with oil cups, start the oil running at a moderate rate. Too little oil will result in heating and injury of the bearings, but, on the other hand, excessive lubrication is unnecessary, wasteful and sometimes productive of harm.

When the dynamo is ready to be started, place the driving belt on the pulley on the armature shaft, and then slip it from the loose pulley or belt holder on to the driving pulley on the countershaft. Tighten the belt by means of the ratchet on the bed-plate, just sufficiently to keep it from slipping. Care should be taken not to put more pressure than is necessary on new bearings; carelessness in this respect is often followed by heating of the boxes, and possible permanent injury.

The brushes may now be let down upon the commutator, and the magnets will be slowly energized. Move the brushes slowly backward or forward by means of the yoke handle until there is no sparking at the lower brushes. Clamp the yoke in this position. If the top brushes then spark, move them slightly, one at a time, forward or backward in the brush holder until their non-sparking point is found.

The spring pressure exerted upon the commutator brushes should be just sufficient to produce a good contact without causing cutting. If the brushes cut, the commutator must be smoothed by the use of sandpaper, not *emery cloth.*

The dynamo should run without load, at the speed given by the manufacturer, and this speed should be uniformly maintained under all conditions. In the case of incandescent dynamos, any increase of speed above that given, shortens the life of the lamps, while a variation below causes unsatisfactory lights.

Before the load is put on, the dynamo should be tested for polarity. This can be done by holding a small pocket compass near the field or pole piece. If the dynamo is connected to be run in multiple with another machine and happens to be polarized wrong, it can be given the right polarity by lifting the brushes from the commutator, closing the field switch and then closing the double-pole switch used to throw it in multiple with the other machine, which is supposed to be now running. After the current has been allowed to pass through the fields for a few moments,

the double-pole switch can be thrown open, and if a test with the compass is again made the polarity will be found to be right, and the dynamo is ready to be started in the usual manner.

In starting for the first time a bipolar dynamo which is to be run in multiple with a spherical armature dynamo, the above instructions should always be followed.

If the dynamo is to be used in series with another on the three-wire system, and is found to be polarized wrong, it can be given the right polarity by making a temporary connection from the positive brush of the new machine to the positive brush of the machine already in operation; and also a temporary connection from negative brush to negative brush, having first raised the brushes from the commutator and closed the field switch. Keep this connection for a few minutes, then open the field switch and break the temporary connections.

Another test with the compass will show that the polarity of the machine is now correct, and the dynamo is ready to be started in the usual manner.

Assuming that the lamps and lines are all ready, the following precautions must be observed when starting the dynamo:

Be very careful that the brushes are properly set and diametrically opposite each other, as explained before.

Be sure that all connections are securely made, and all nuts on the connection boards firmly set.

In cases where two or more dynamos are connected in multiple by the use of the equalizing connection, care should be taken that the circuit wires from both positive brushes are connected to the same side of the main line, while those from the negative are connected to the other side.

A neat arrangement of the equalizing connection can be made by using triple-pole switches on the switchboard, instead of double-pole switches, and making the equalizing connections through the center pole of the switch, instead of running a cable direct from one dynamo to the other. This method is especially desirable where three or more dynamos are run in multiple.

When dynamos are connected in series, as in the cases where the three-wire system is in use, the leading wire from the positive

brush of one machine is connected to the negative brush of the other. The other two brushes (negative and positive) are connected to the main wire on the outside of the system, while the third or center wire is connected to the conductor between the two dynamos.

Dust or Gritty Substances. All insulations should be carefully cleaned at least once a day.

If any of the connections of the machine become heated, examination will show that the metal surfaces are not clean or not in perfect contact. Avoid the use of water or ice on the bearings in case of accidental heating, as the water may get to the armature and injure the insulation.

The Commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary, unless the brushes cut, and then only at the point of cutting. A cloth slightly greased with vaseline is best for the purpose. Never use sandpaper on the commutator without first lifting the brushes. Otherwise the grit will stick to the brushes and cut the commutator.

Brushes. Care should be taken to keep copper commutator brushes in good shape, and not to allow them to be worn out of square; that is, too much to one side, so that the end is not worn at right angles to the lateral edges.

When the machine is not running, the brushes should always be raised from the commutator. The brushes should be kept carefully cleaned, and no oil or dirt allowed to accumulate upon them. This can be done by washing them occasionally in benzine or in a hot solution of soda ash.

Manufacturers usually furnish a gauge, which should be used occasionally to test the wearing of the brushes. If they are found to be worn either too flat or too blunt, they should be filed in proper shape, or, better still, ground on a grindstone. Carbon brushes require less care. Spindles upon which the brush holders are arranged to slide should be cleaned with emery cloth often enough to prevent tarnishing or the collection of dirt, which might cause heating by impairing the electrical connection.

Brush holders that can be moved laterally on the spindle by

which they are supported, should be so arranged that the top and bottom brushes will bear on different parts of the length of the commutator, for the purpose of distributing the wear more uniformly.

In case of a **hot box** the most natural thing to do is to shut the machine down, but this should never be done until the following alternatives have been tried and failed:

First—Lighten the load.

Second—Slacken the belt.

Third—Loosen the caps on the boxes a little.

Fourth—Put more oil in bearings.

Fifth—If all the above fail to remedy the heating, use a heavy lubricant, such as vaseline or cylinder oil. Should the heating then diminish, the shaft must be polished with crocus cloth and the boxes scraped at the end of the day.

Sixth—Under no conditions put ice upon the bearing, unless you are perfectly familiar with such a procedure.

Seventh—If it is absolutely necessary to shut down, get the belt off as soon as possible, keeping the machine revolving meanwhile in order to prevent sticking, and at the same time take off the caps of the bearings. Do not stop the flow of oil to the bearings. When the caps have been taken off, stop the machine and get the linings out immediately, and allow them to cool in the air. Do not throw the linings into cold water, as it is liable to spring them.

Scraping should be done only by an experienced person, otherwise the linings may be ruined. Polish the shaft with crocus cloth, or, if badly cut, file with a very fine file, and afterwards polish with crocus.

Wipe the shaft, as well as the boxes, very carefully, as perhaps grit has been the cause of the hot box. Inspect the bearings; see that they are in line, that the shaft has not been sprung, and that the oil collar does not bear against the box.

Oily Waste should be kept in approved metal cans (made entirely of metal, with legs raising them at least three inches above the floor and with self-closing covers), and removed daily.

A competent man should always be kept on duty where generators are operating.

THE INSTALLATION OF MOTORS.

All motors should be insulated on floors or base frames, which should be kept filled to prevent absorption of moisture; also they should be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame should be permanently and effectively grounded.

A high-potential machine which on account of great weight or for other reasons cannot have its frame insulated, should be surrounded with an insulated platform. This may be of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor, to provide for the inevitable overloading of the motor at times, without over-fusing the wires.

The motor and resistance box should be protected by a cutout or circuit breaker, and controlled by a switch, the switch plainly indicating whether "on" or "off." Where one-fourth horse power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat should be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

In connection with motors the use of circuit breakers, automatic starting boxes and automatic under-load switches is recommended, wherever it is possible to install them.

Motors should not be run in series, multiple, or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

Like generators, they should be covered with a waterproof cover when not in use, and if necessary, should be inclosed in an approved case.

Motors, when combined with ceiling fans, should be hung from insulated hooks, or there should be an insulator interposed between the motor and its support.

Every motor should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

One rule at all times to be remembered in starting and stopping motors is, *Switch first, rheostat last,* which means, in starting, close the switch first, and then gradually cut out all resistance as the motor speeds up, and to stop the motor open the switch first and then cut in all the resistance of the rheostat which is in series with the motor armature.

When starting any new motor for the first time, see that the belt is removed from the pulley and the motor started with no load. Never keep the rheostat handle on any of its coils longer than a moment, as they are not designed to regulate the speed of the motor but to prevent too large a flow of current into the armature before the latter has attained its full speed.

Fig. 1 shows a rheostat which is designed to protect automatically the armature of a motor. The contact arm is fitted with a spring which constantly tends to throw the arm on the "off point" and open the circuit, but is prevented from so doing, while the motor is in operation, by the small electro-magnet, shown on the face of the rheostat, which consists of a low-resistance coil connected in series with the field winding of the motor. This magnet holds the contact arm of the rheostat in the position allowing the maximum working current to flow through the armature while it is in operation.

If, for any reason, the current supplied to the motor be momentarily cut off, the speed of the armature generates a counter current which also tends to hold the arm in position as long as there is any motion to the motor armature; but as soon as the armature ceases to revolve, all current ceases to flow through the electro-magnet, thereby releasing the rheostat handle, which flies back to the "off point," as shown in the illustration, and the moter armature is out of danger. Such a device is of great value where inexperienced men have to handle motors, and are unaware that the first thing to be done when a motor stops, for any reason whatever, is to open the circuit, and then cut in all the resistance in the rheostat to prevent too large an in-rush of current when the motor is started up again.

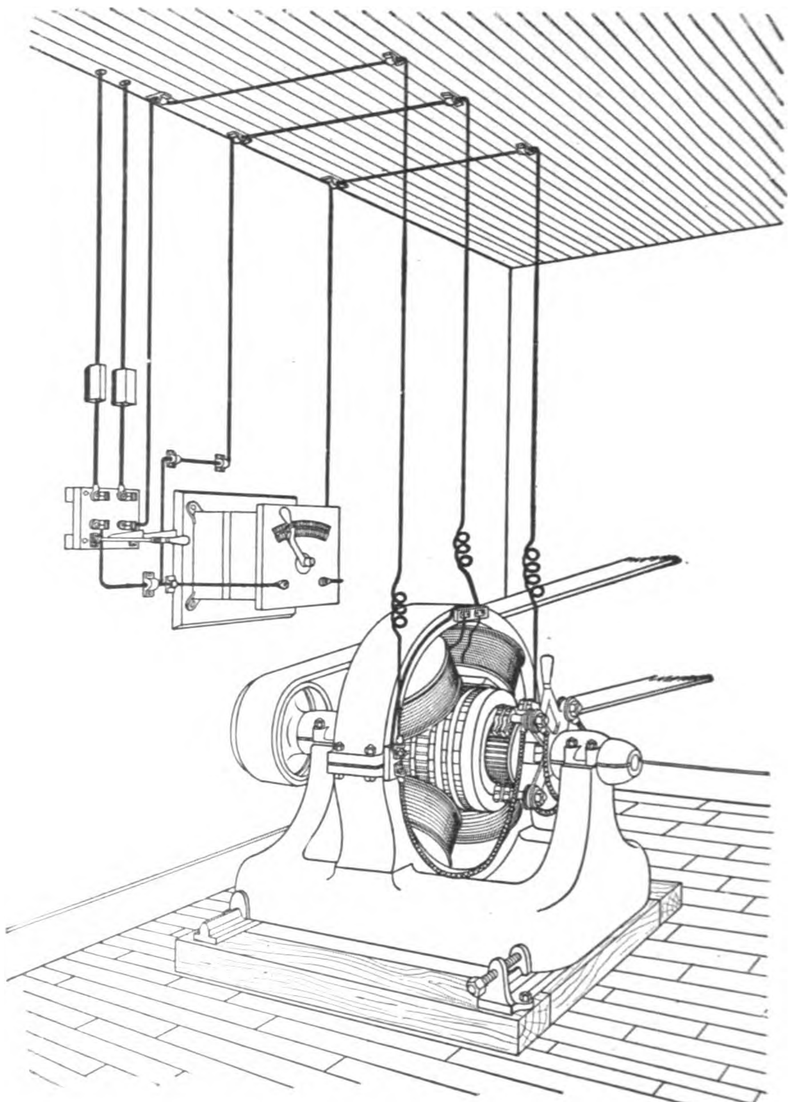


Fig. 1.

An approved installation in every detail; wiring connections for shunt-wound 4-pole motor, using double-pole fuse cut-out instead of circuit breaker.

The Circuit Breaker for under and over loads is also a most valuable protection in such cases.

Motor Wiring Formulæ—(Direct Current). To find the size of wire, in circular mils, required to transmit any power any distance at any required voltage and with any required loss, we have the following formula. Having found the required number of circular mils, it is advisable to add 50 per cent more for safety.

e=potential of motor. d=distance from generator to motor.

v=volts lost in lines. K=efficiency of motor.

10.8 = resistance in ohms of 1 foot of 97 per cent pure copper wire one mil in diameter.

$$\text{c.m.} = \frac{\text{h. p. of motor} \times 746 \times 2d \times 10.8 \times 100}{e \times v \times K}$$

To find size of wire from c.m., see table, page 37.

AVERAGE MOTOR EFFICIENCY.

1 h. p.	75 per cent
3 h. p.	80 per cent
5 h. p.	80 per cent
10 h. p. and over	90 per cent

For Most Cases—(Small Installations). The table and examples worked out on pages 38, 39 and 40 will give the desired results without the above formulæ.

To find current required by a motor when the horse power, efficiency and voltage are known, use the following formula:

Let C = current to be found. H. P. = horse power of motor.
E = voltage of motor circuit. K = efficiency of motor.

$$C = \frac{\text{H. P.} \times 746 \times 100}{E \times K}$$

Or, when possible, use table I.

By adding the volts indicated in table II. to the voltage of the lamp or motor, the result shows the voltage at the dynamo for losses indicated. Thus 10 per cent on 110-volt system is: 12.22 volts added to 110 equal 122.22, showing that the dynamo must generate 122.22 volts for a 10 per cent loss.

TABLE I.

Amperes Per Motor.

H. P.	Per Cent.	Watts	THE TOP ROW INDICATES VOLTS. 50	75	110	220	400	500	600	800	1000	1200
¾	75	746	14.9	9.94	6.79	3.38	1.86	1.48	1.24	.93	.746	.62
1½	75	1492	29.8	19.8	13.56	6.78	3.73	2.98	2.48	1.86	1.492	1.24
3	80	2797	55.9	37.2	25.4	12.7	6.99	5.59	4.66	3.49	2.797	2.33
5	80	4662	93.2	62.1	42.3	21.1	11.65	9.32	7.77	5.82	4.662	3.88
7½	90	6217	124.	82.9	56.5	28.2	15.54	12.43	10.36	7.77	6.217	5.18
10	90	8288	165.	110.	75.5	37.6	20.72	16.57	13.81	10.36	8.288	6.90
15	90	12433	248.	165.	113.	56.5	31.08	24.86	20.72	15.53	12.43	10.36
20	90	16578	331.	221.	150.	75.3	41.44	33.15	27.63	20.72	16.57	13.98
25	90	20722	414.	276.	188.	94.1	51.8	41.6	34.5	25.9	20.7	17.2
30	90	24866	497	331.	226.	113.	62.	49.7	41.4	31.	24.8	20.7
40	90	33155	663.	442.	301.	150.	82.8	66.3	55.2	41.4	33.1	27.6
50	90	41444	828.	552.	376.	188.	103.	82.8	69.	51.8	41.4	34.5
60	90	49733	994.	663.	452.	226.	124.	99.4	82.8	62.	49.7	41.4
70	90	58022	1160.	773.	527.	263.	145.	116.	96.7	72.5	58.	48.3
80	90	66311	1326.	884.	602.	301.	165.	132.	110.	82.9	66.3	55.2
90	90	74599	1491.	994.	678.	339.	186.	149.	124.	93.	74.5	62.
100	90	82888	1657.	1105.	753.	376.	207.	165.	138.	103.	82.8	69.
120	90	99457	1989.	1326.	904.	452.	248.	198.	165.	124.	99.	82.8
150	90	124312	2486.	1657.	1131.	565.	310.	248.	207.	155.	124.	103.

TABLE II.

Volts Lost at Different Per Cent Drop.

Drop per cent.	VOLTAGE.											
	52	75	100	110	220	400	500	600	800	1000	1200	2000
½	.261	.376	.502	.552	1.10	2.01	2.51	3.01	4.02	5.02	6.03	10.05
1	.525	.757	1.01	1.11	2.22	4.04	5.05	6.06	8.08	10.10	12.12	20.2
1½	.2918	1.14	1.52	1.67	3.35	6.09	7.61	9.13	12.1	15.2	18.2	30.4
2	1.06	1.53	2.04	2.24	4.48	8.16	10.2	12.2	16.3	20.4	24.4	40.8
2½	1.33	1.92	2.56	2.82	5.64	10.25	12.8	15.3	20.5	25.6	30.7	51.2
3	1.61	2.31	3.09	3.40	6.80	12.37	15.4	18.5	24.7	30.9	37.1	61.8
4	2.16	3.12	4.16	4.58	9.16	16.66	20.8	24.9	33.3	41.6	49.9	83.3
5	2.73	3.94	5.26	5.78	11.57	21.05	26.3	31.5	42.1	52.6	63.1	105.
6	3.31	4.78	6.38	7.02	14.04	25.53	31.9	38.2	51.	63.8	76.5	127.
7	3.91	5.64	7.52	8.27	16.55	30.10	37.6	45.1	60.2	75.2	90.3	150.
8	4.52	6.52	8.69	9.56	19.13	34.78	43.4	52.1.	69.5	86.9	104.	173.
9	5.14	7.41	9.89	10.87	21.75	39.56	49.4	59.3	79.1	98.9	118.	197.
10	5.77	8.33	11.11	12.22	24.44	44.44	55.5	66.6	88.8	111.	133.	222.
11	6.42	9.26	12.35	13.59	27.19	49.43	61.7	74.1	98.8	123.	148.	247.
12	7.09	10.22	13.63	14.99	29.99	54.54	68.1	81.8	109.	136.	163.	272.
13	7.76	11.10	14.94	16.43	32.87	59.76	74.7	89.6	119.	149.	179.	298.
14	8.46	12.20	16.27	17.90	35.81	65.1	81.3	97.6	130.	162.	195.	325.
15	9.17	13.23	17.64	19.41	38.82	70.5	88.2	105.	141.	176.	211.	352.
20	13.	18.75	25.	27.50	55.	100.	125.	150.	200.	250.	300.	400.
25	17.33	25.	33.33	36.66	73.33	133.	166.	200.	266.	333.	400.	666.

OUTSIDE WIRING AND CONSTRUCTION.

Service Wires (those leading from the outside main wire to the buildings and attached to same) should be "Rubber-Covered."

Line Wires, other than service wires, should have an approved "weatherproof covering."

Bare Wires may be used through uninhabited and isolated territories free from all other wires, as in such places wire cover-

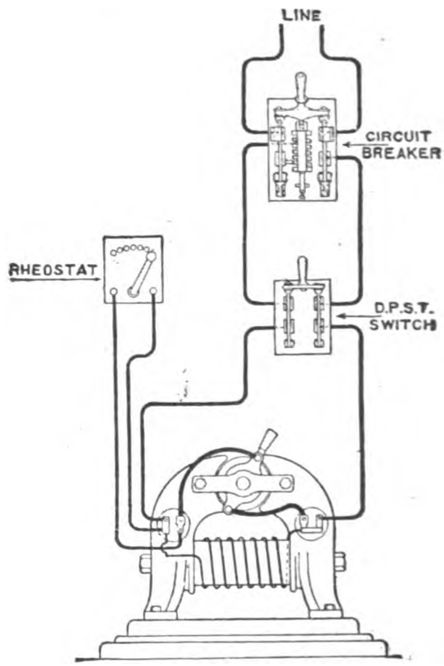
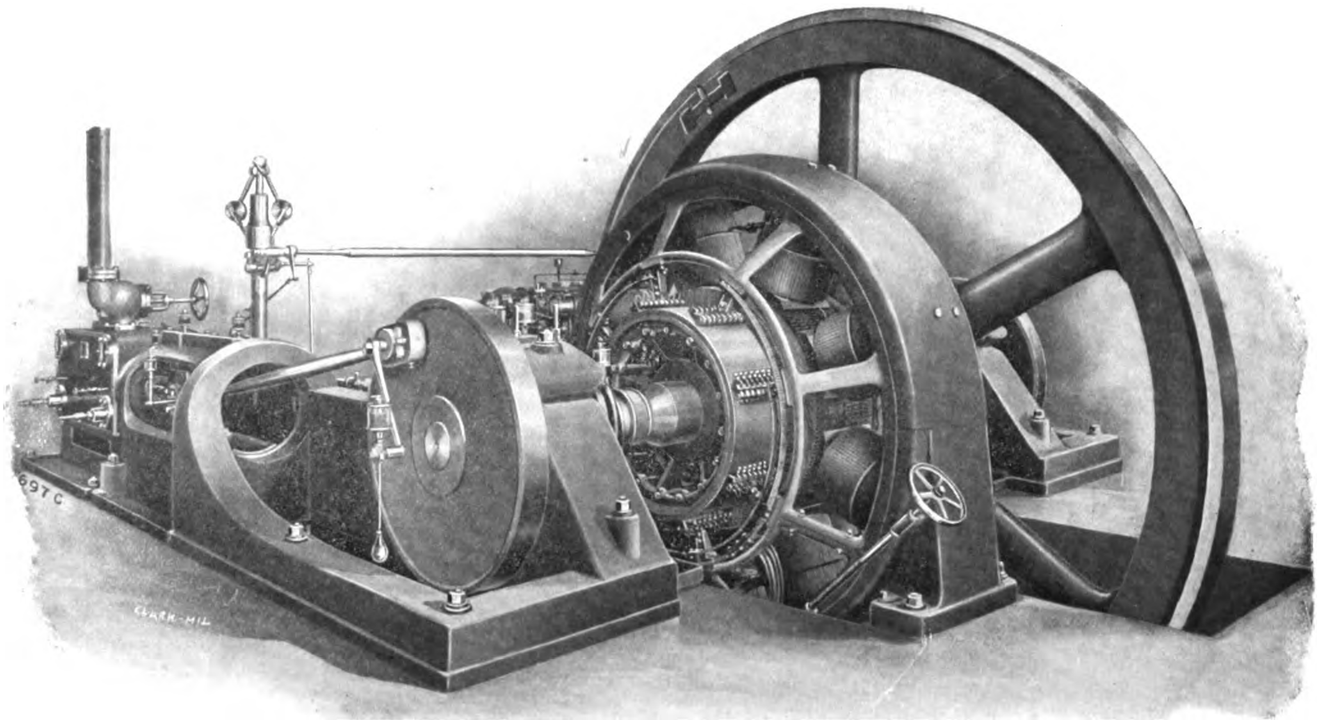


Fig. 2.

An approved installation in every detail; wiring connections for shunt-wound bipolar motor, using circuit breaker instead of double-pole fuse cut-out.

ing would be of little use, as it is not relied on for pole insulation, and is not needed for other purposes, because the permanent insulation of the wires from the ground is assured by the glass or porcelain petticoat insulators to which the wires are secured.

Tie Wires should have an insulation equal to that of the conductors they confine.



"NATIONAL" ENGINE-TYPE GENERATOR

200 K.W. 250 Volt, 135 R.P.M.

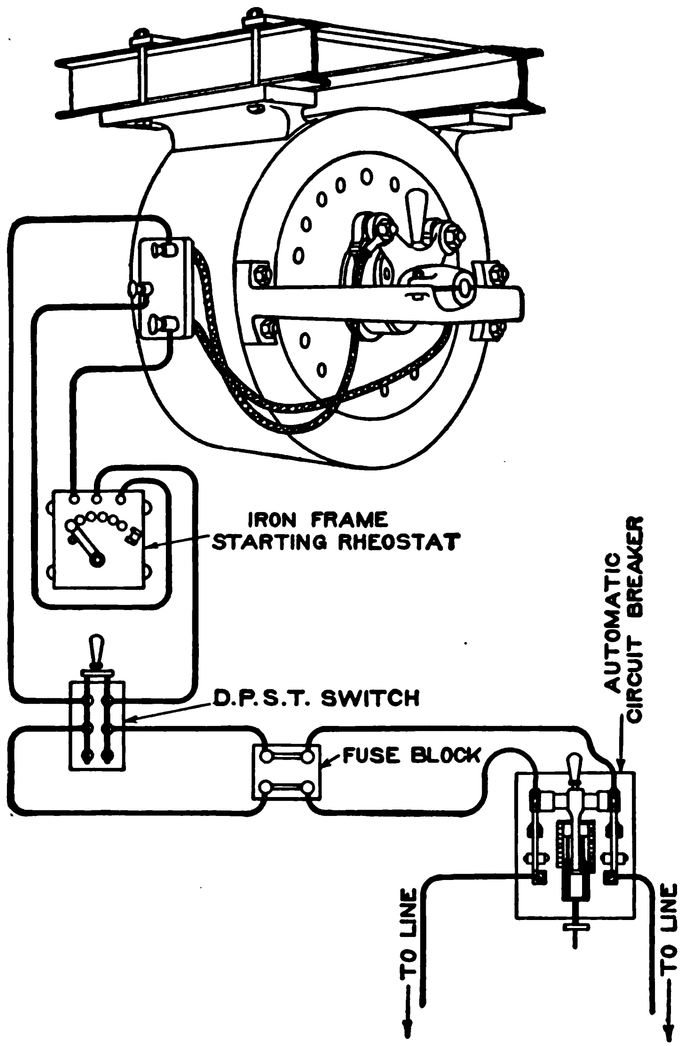


Fig. 3.

An approved installation in every detail, with wiring connections for shunt-wound multipolar slow speed ceiling motor for direct connection to line shaft. Using both circuit breaker and double-pole fuse cut-out.

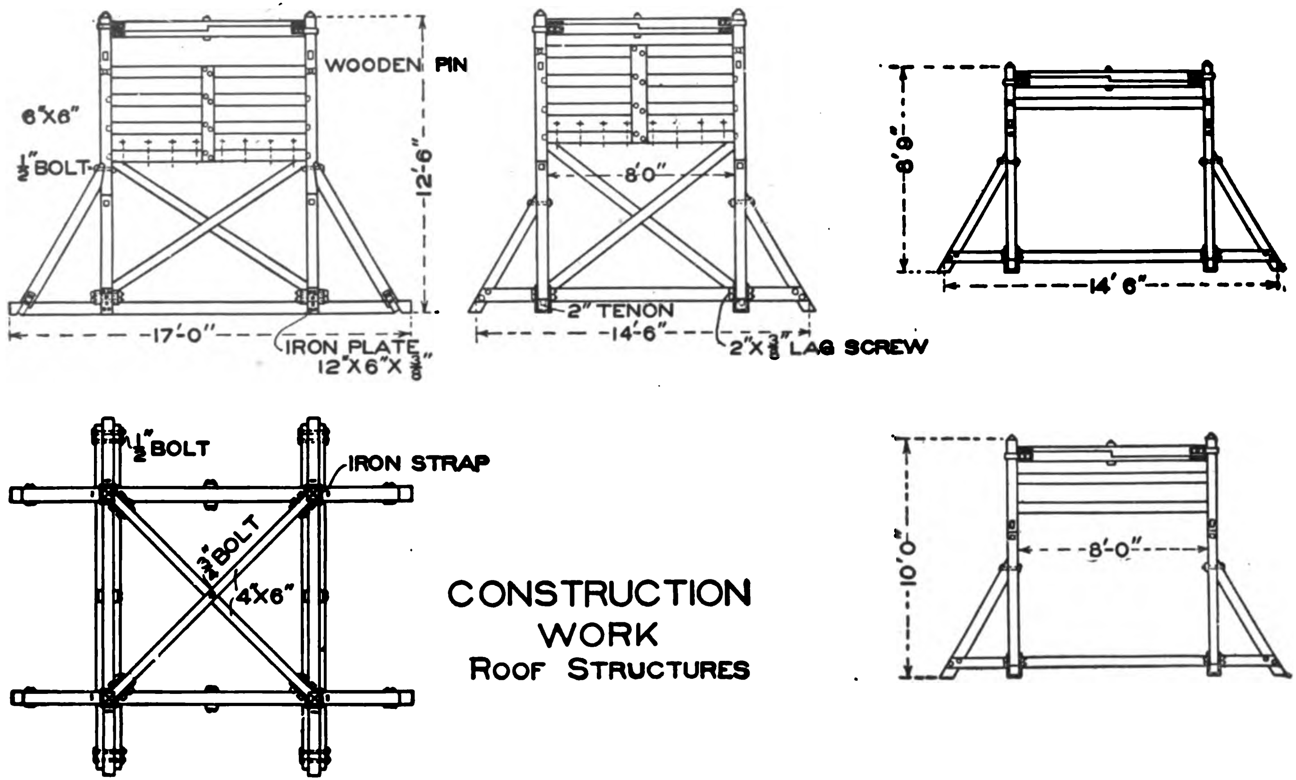

WOODEN PIN
6"X6"
1/2" BOLT
12'-6"
-17'-0"-
IRON PLATE 12"X6"X 3/8"
8'-0"
2" TENON
-14'-6"-
2"X 3/8" LAG SCREW
8'-9"
14' 6"
1/2" BOLT
IRON STRAP
3/4" BOLT
4"X6"
CONSTRUCTION
WORK
ROOF STRUCTURES
10'-0"
8'-0"

Fig. 4.

Space Between Wires for outside work, whether for high or low tension, should be at least one foot, and care should be exercised to prevent any possibility of a cross connection by water. Wires should never come in contact with anything except their insulators.

Roof Structures. If it should become necessary to run wires over a building, the wires should be supported on racks which will raise them seven feet above flat roofs or at least one foot above the ridge of pitched roofs. See Fig. 4.

Guard Arms. Whenever sharp corners are turned, each cross arm should be provided with a dead insulated guard arm to prevent the wires from dropping down and creating trouble, should their insulating support give way.

Petticoat Insulators should be used exclusively for all outside work, and especially on cross arms, racks, roof structures and service blocks. Porcelain knobs, cleats or rubber hooks should never be used for this heavy outside work.

Splicing of two pieces of wire or cable should be done in such manner as to be mechanically and electrically secure without solder. The joints should then be soldered to prevent corrosion and consequent bad contact. All joints thus made should be covered with an insulation equal to that of the conductors.

Tree Wiring. Whenever a line passes through the branches of trees, it should be properly supported by insulators, as shown in Fig. 5, to prevent the chafing of the wire insulation and grounding the circuit.

Service Blocks which are attached to buildings should have at least two coats of waterproof paint to prevent the absorption of moisture.

Entrance Wires. Where the service wires enter a building they should have drip loops outside, and the holes through which the conductors pass should be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside. See Fig. 6.

Telegraph and Telephone wires should never be placed on the same cross-arm with light or power wires, especially when alternating currents are used, as trouble will arise from induc-

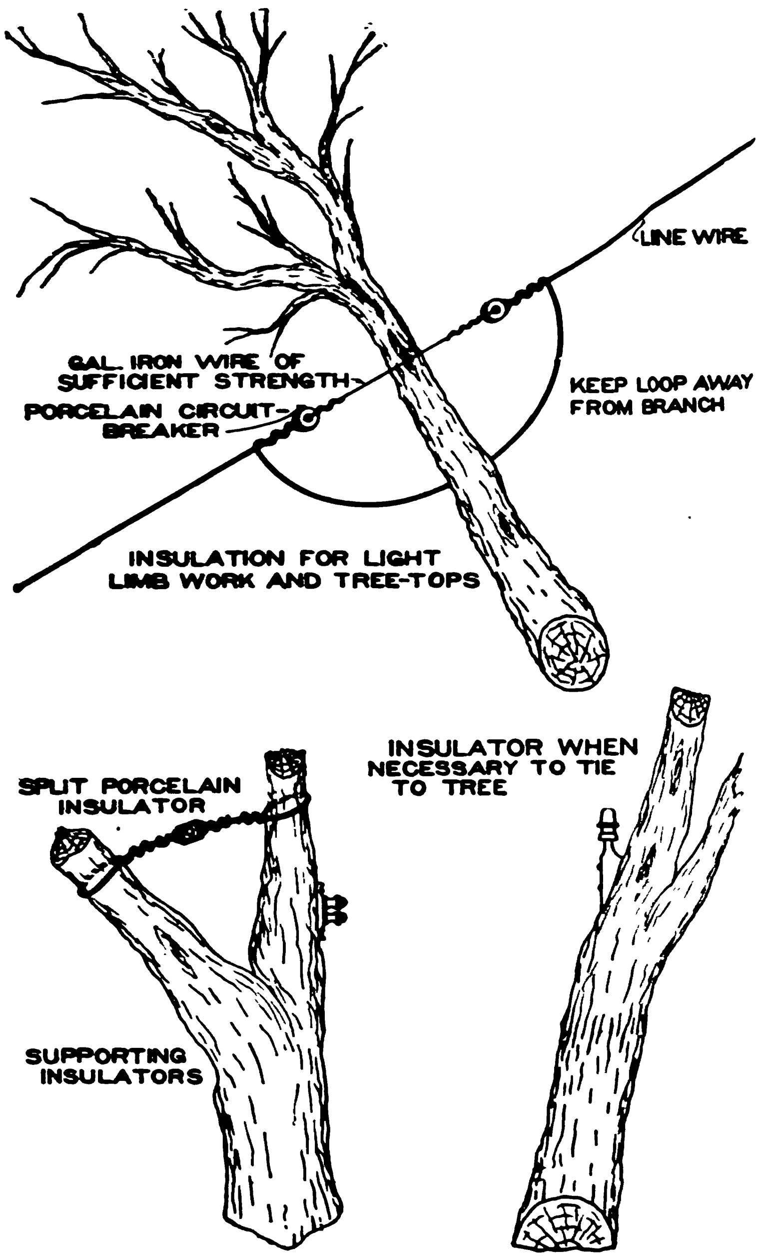

LINE WIRE
KEEP LOOP AWAY FROM BRANCH
GAL. IRON WIRE OF SUFFICIENT STRENGTH
PORCELAIN CIRCUIT-BREAKER
INSULATION FOR LIGHT LIMB WORK AND TREE-TOPS
INSULATOR WHEN NECESSARY TO TIE TO TREE
SPLIT PORCELAIN INSULATOR
SUPPORTING INSULATORS

Fig. 5.

tion, unless expensive special construction, such as the transposing of the lighting circuits, be resorted to at regular intervals. Even under these conditions it is bad practice, as an accidental contact with the lighting or power circuit might result in starting a fire in the building to which the telephone line is connected. If, however, it is necessary to place telegraph or telephone wires on the same poles with lighting or power wires, the distance between the two inside pins of each cross-arm should not be less than twenty-six inches, and the metallic sheaths to cables should be thoroughly and permanently connected to earth.

Transformers should not be placed inside of any buildings except central stations, and should not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

In cases where it is impossible to exclude the transformer and primary wiring from entering the building, the transformer should be located as near as possible to the point where the primary wires enter the building, and should be placed in a vault or room constructed of or lined with fire-resisting material, and containing nothing but the transformer. In every case the transformer must be insulated from the ground and the room kept well ventilated. It is of course the safest and best practice to place all transformers on poles away from the building that is to be lighted, as illustrated in Fig. 7.

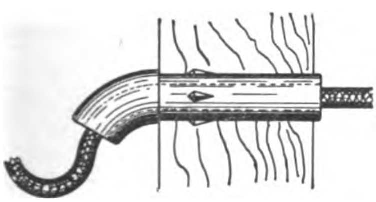


Fig. 6.
Porcelain tube, used where wires enter buildings, showing drip loop in wire.

The Grounding of Low-Potential Circuits is allowed only when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

In Direct-Current 3-Wire Systems the neutral wires may be grounded, and when grounded the following rules should be complied with:

1. They should be grounded at the central station on a metal plate buried in coke beneath permanent moisture level, and

also through all available underground water and gas pipe systems.

2. In underground systems the neutral wire should also be grounded at each distributing box through the box.

3. In overhead systems the neutral wire should be grounded every 500 feet.

When grounding the neutral point of transformers or the

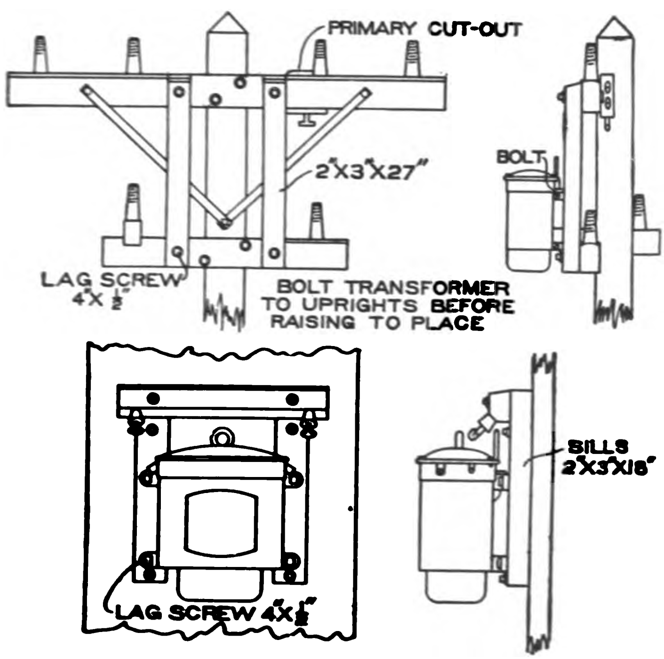


Fig. 7.
Construction work; installing transformers.

neutral wire of distributing systems the following rule should be complied with:

1. Transformers feeding two-wire systems should be grounded at the center of the secondary coils, and when feeding systems with a neutral wire, should have the neutral wire grounded at the transformer, and at least every 500 feet for underground systems.

In making ground connections on low-potential circuits, the ground wire in direct-current 3-wire systems should not at central

stations be smaller than the neutral wire, and not smaller than No. 6 B. & S. elsewhere.

In Alternating-Current Systems the ground wire should never be less than No. 6 B. & S., and should always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are banked.

These wires should be kept outside of buildings, but may be directly attached to the building or pole, and should be carried in as nearly a straight line as possible, all kinks, coils and sharp bends being avoided.

The ground connection for central stations, transformer substations, and banks of transformers should be made through metal plates buried in coke below permanent moisture level, and connection should also be made to all available underground piping systems, including the lead sheath of underground cables.

For individual transformers and building services the ground connection may be made to water or other piping systems running into the buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main cocks, etc., but connection should never be made to any lead pipes which form part of gas services.

In connecting ground wires to piping systems, wherever possible, the wires should be soldered into one or more brass plugs and the plugs forcibly screwed into a pipe fitting, or, where the pipe is cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance. Where such plugs cannot be used, the surface of the pipe may be filed or scraped bright, the wire wound around it, and a strong clamp put over the wire and firmly bolted together.

Where ground plates are used, a No. 16 copper plate, about 3 by 6 feet in size, with about two feet of crushed coke or charcoal, about pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary sub-station or bank of transformers. For a large central station considerable more area might be neces-

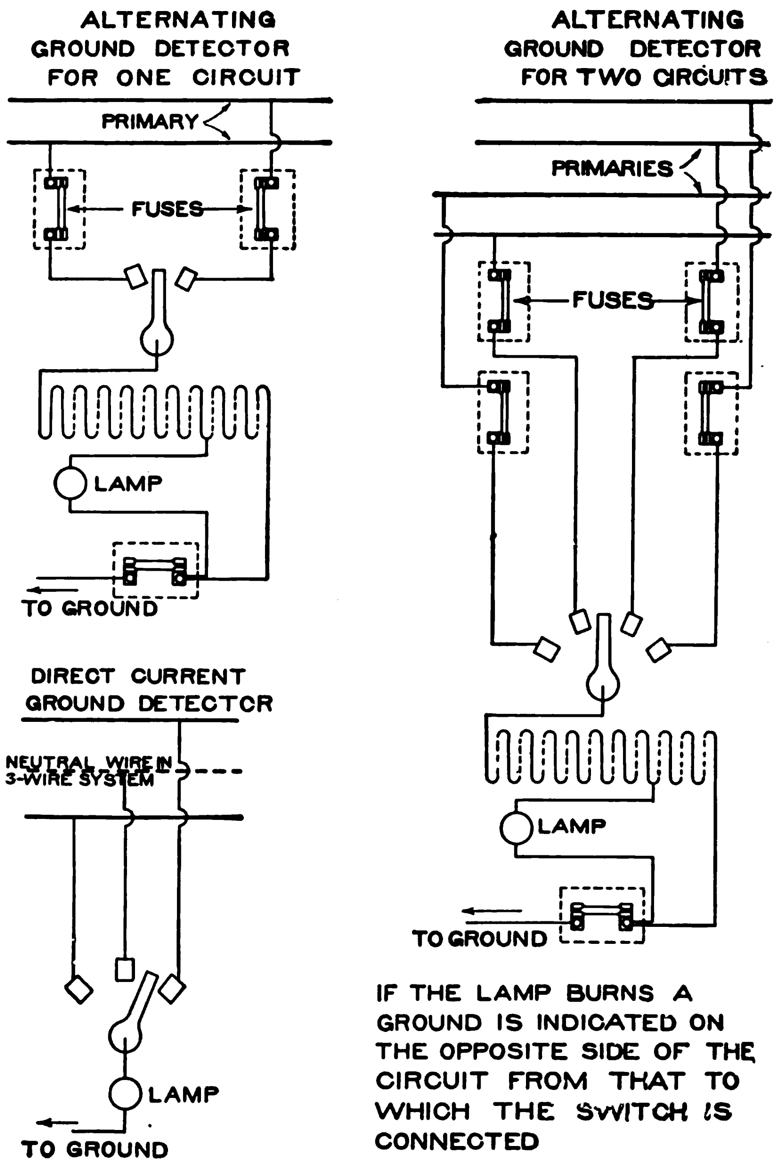


Fig. 8.

Connections of Ground Detectors.

sary, depending upon the underground connections available. The ground wire should be riveted to such a plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast iron plate, brass plugs being screwed into the plate to which the wire is soldered. In all cases, the joint between the plate and the ground wire should be thoroughly protected against corrosion, by suitable painting with waterproof paint or some equivalent.

Ground Detectors. Fig. 8 illustrates a few practical methods of detecting grounds on alternating and direct-current circuits which have not been purposely grounded.

In using any one of these methods for detecting grounds, always see that the circuit to ground is left open after testing the outside circuits.

Some central station men are in the habit of leaving the ground circuit closed on one side constantly in order that any ground that might occur on the other side may be instantly noticed. This, however, is bad practice, as it greatly reduces the insulation of the whole system. Test all circuits at least once a day.

It is sometimes necessary to know just what the insulation resistance of a line, or of the wiring in a building, is in ohms. This can be found very readily, and closely enough for all practical purposes, by using a Weston volt meter in the following manner:

Connect with a wire from one side of the circuit to one binding post of the volt meter, and with another piece of wire connect a water pipe to the other binding post of the volt meter. If the needle or pointer shows any deflection we know there is a ground, or leakage, on the opposite side of the circuit to which the volt meter is connected.

The resistance of this ground leak may be found by the following formula:

$R = r\left(\frac{V}{v} - 1\right)$ ohms when R = resistance of ground leak required, r = resistance of volt meter, V = voltage between the positive and negative sides of the line, v = reading in volts, on the instrument, produced by the leakage.

Primary Wiring. Primary wires should be kept at least ten inches apart, and at that distance from conducting material. Primary wires carrying over 3,500 volts should not be brought into or over any building other than the central power station or sub-station.

Wires for Outside Use have in most cases a "weatherproof" insulation, except service wires, which should be "rubber-covered." Any insulating covering for wires exposed to the weather on poles is in a short time rendered useless. The real insulation of the system will be found to be dependent upon the porcelain or glass insulators.

POLES FOR LIGHT AND POWER WIRES.

It is essential to a proper installation that the poles receive due consideration, a fact that is too often overlooked.

In selecting the style of pole necessary for a certain class of work the conditions and circumstances should be considered. Poles may be arranged in three classes, the size of wire which they are to carry respectively being one of the important regulating circumstances.

First Class: Alternating-current plants for lighting small towns. Main line of poles should consist of poles from 30 to 35 feet long, with 6-inch tops. These are strong enough for all the weight that is placed upon them. No pole less than 30 feet with 6-inch top should be placed on a corner for lamps. The height of trees, of course, must be considered in many cases. For the Edison municipal system, where more than one set of wires are used for street lighting, a 6-inch top should be the size of the poles, the length being not less than 30 feet, and greater than this if the streets be hilly and filled with trees.

Second Class: Town lighting by arc lights. All poles should be at least 6-inch tops. The corner poles should be 6½-inch tops; and wherever the cross-arms are placed on a pole at different angles, the pole should be at least a 6½-inch top. A 30-foot pole is sufficiently long for the main line, but it would be advisable to place 35-foot poles on corners.

Third Class: Where heavy wire, such as No. 00, is used for feeder wire, the poles should be at least 7-inch tops. Where mains are run on the same pole line the strain is somewhat lessened, and poles of smaller size will answer all purposes.

Cull Poles. The question as to what is a cull pole is something on which many authorities differ. Of course, if specifications call for a certain sized pole, parties supplying the poles should be compelled to send the sizes called for. All poles that are smaller at the top than the sizes agreed upon, are troubled with dry rot, large knots and bumps, have more than one bend, or have a sweep of over twelve inches, should certainly be classed as cull poles. Specifications for electric light and power work should be, and in many cases are, much more severe than those required by telegraph lines. A cull pole, one of good material, is the best thing for a guy stub, and is frequently used for this purpose. A cedar pole is always preferable to any other, owing to the fact that it is very light compared with other timber, and is strong, durable and very long lived.

Pole Setting. It seems to be the universal opinion of the best construction men that a pole should be set at least five feet in the ground, and six inches additional for every five feet above thirty-five feet. Also additional depths on corners. Wherever there is much moisture in the ground, it is well to paint the butt end of the pole, or smear it with pitch or tar, allowing this to extend about two feet above the level of the ground. This protects the pole from rot at the base. The weakest part of the pole is just where it enters the ground. Never set poles farther than 125 feet apart; 110 feet is good practice.

Pole Holes should be dug large enough so that the butt of the pole can be dropped straight in without any forcing, and when the pole is in position only one shovel should be used to fill in, the earth being thoroughly tamped down with iron tampers at every step until the hole is completely filled with solidly packed earth. Where the ground is too soft for proper tamping, a grouting composed of one part of Portland cement to two parts of sand, mixed with broken stone, may be used to make an artificial foundation.

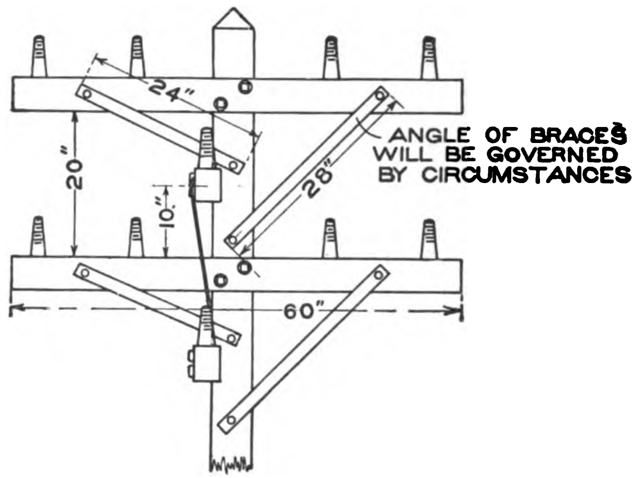


FIG. 1

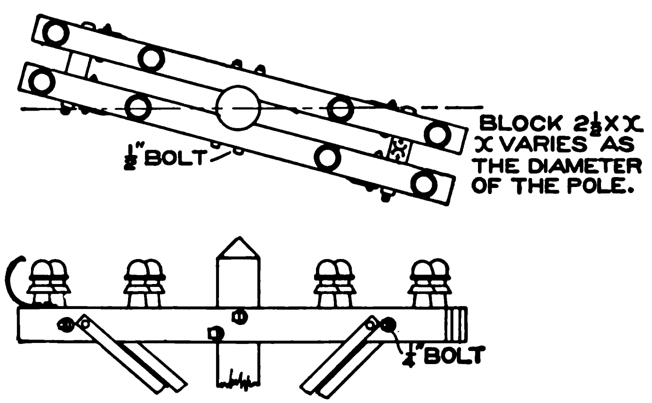


FIG. 2

Fig. 9.

CONSTRUCTION WORK; POSITION OF CROSS-ARMS WHEN TURNING CORNERS.

When running a heavy line wire it is necessary to use two cross-arms fastened as shown above in Fig. 2. If lines are not heavy, only one cross-arm will be necessary. In case lines cross the street diagonally, the arms where the wires leave and those to which they run are both set at an angle. When turning an abrupt corner only one arm is turned. The above cannot be used where feeders tap into double branches. In such a case the method given in Fig. 1 is used.

TABLE III.

Cedar Poles for Electric Light Work.

SIZE.	Average weight, pounds each.	No. of Poles to a Car.	SIZE.	Average weight, pounds each.	No. of Poles to a Car.
25 ft., 5-inch top	200	150	35 ft., 7-inch top	650	90
25 " 5½ " "	225	130	40 " 6 " "	800	80
25 " 6 " "	250	120	40 " 7 " "	900	75
28 " 7 " "	400	80	45 " 6 " "	900	70
30 " 5 " "	300	110	45 " 7 " "	1000	65
30 " 6 " "	350	90	50 " 6 " "	1200	55
30 " 7 " "	420	75	55 " 6 " "	1400	45
35 " 6 " "	550	100			

Painting. When poles are to be painted, a dark olive green color should be chosen, in order that they may be as inconspicuous as possible. One coat of paint should be applied before the pole is set, and one after the pole is set. Tops should be pointed to shed water.

All poles 35 feet long and over must be loaded on two cars.

For chestnut poles add 50 per cent to weights as given in table.

Cross-Arms. The distance from the top of the pole to the cross-arm should be equal to the diameter of pole at the top. All cross-arms should be well painted with one coat of paint before placing, and must be of standard size as shown in the diagrams. Cross-arms of four or more pins should be braced, using one or two braces as occasion demands. Cross-arms on one pole should face those on the next, thereby making the cross-arms on every other pole face in one direction. All pins should have their shanks dipped in paint and should be driven into the cross-arm while the paint is wet. The upper part of the pin should also be painted. Iron pins may be furnished for corners where there is a heavy strain, but are not advised, it being preferable to use the construction as shown in the diagrams. Put double arms on the pole where feeder wires end.

Guard Irons. Guard irons should be placed at all angles in lines, and on break-arms.

Steps. All junction and lamp poles should be stepped so that the distance between steps on the same side of the pole will not be over 36 inches. Poles carrying converters should also be stepped.

TABLE IV.
Pole Line Data.

Gauge Number (B. & S.)		4/0	3/0	2/0	1/0	1	2	3	4	5	6	7	8
Diam. of Bare Wire, in Thousandths		.460	.40964	.3648	.3249	.2893	.2576	.2294	.2043	.1819	.1620	.1442	.1285
Ohms Res. B. Wire per Mile, 75° Fahr.		.25902	.32667	.41188	.5499	.6910	.8719	1.099	1.400	1.754	2.213	2.812	3.539
Wt. (lbs.) per 1000 feet Insulated Wire		826	611	460	357	300	244	204	168	119	100	84	71
Weight per Mile (approximate) of Insulated Wire		4360	3225	2225	1880	1580	1285	1075	885	625	525	440	373
No. of Poles per Lineal Mile.	Distance Between Poles (feet).	Approximate Weight of Insulated Wire Between Poles.											
20	264.00	218.0	161.3	121.3	94.0	79.0	64.25	53.75	44.25	31.2	26.25	22.	18.65
21	251.40	208.0	153.6	115.5	89.53	75.0	61.2	51.2	42.2	30.0	25.0	20.96	17.8
22	240.10	198.2	146.6	110.3	85.5	71.9	58.5	48.9	40.3	28.41	23.9	20.0	16.96
23	229.56	189.69	140.3	105.5	81.74	68.70	55.88	46.8	38.5	27.17	22.83	19.2	16.22
24	220.00	181.7	134.4	101.0	78.34	65.84	53.54	44.8	36.91	26.05	21.9	18.34	15.55
25	211.20	174.4	129.	97.0	75.20	63.2	51.40	53.0	35.4	25.0	21.0	17.6	14.92
26	203.07	167.7	124.04	93.3	72.40	60.8	49.42	41.34	34.04	24.04	20.19	16.93	14.35
27	195.55	161.5	119.5	89.81	69.63	58.52	47.22	40.00	32.77	23.15	19.45	16.30	13.82
28	188.55	155.7	115.2	86.61	67.50	56.43	45.90	38.39	31.61	22.33	18.76	15.72	13.33
29	182.09	150.34	111.3	83.62	64.82	54.48	44.31	37.07	30.52	21.56	18.11	15.18	12.87
30	176.00	145.34	107.5	80.85	62.67	52.67	42.84	35.84	29.50	20.86	17.50	14.67	12.44
31	170.30	140.65	104.04	78.23	60.65	50.97	41.46	34.68	28.55	20.17	16.94	14.20	12.04
32	165.00	136.25	100.80	75.80	58.75	49.38	40.16	33.60	27.66	19.54	16.41	13.75	11.72
33	160.00	132.13	97.73	73.49	56.97	47.88	38.94	32.58	26.82	18.94	15.91	13.34	11.31
34	155.29	128.24	94.86	71.83	55.30	46.48	37.80	31.62	26.03	18.39	15.45	12.95	10.98
35	150.85	124.58	92.15	69.29	53.72	45.15	36.73	30.72	25.29	17.86	15.00	12.58	10.66
36	146.66	121.12	89.59	67.37	52.23	43.89	35.70	29.87	24.59	17.37	14.59	12.23	10.37
37	142.70	117.84	87.17	65.55	50.82	42.71	34.73	29.06	23.92	16.90	14.19	11.90	10.09
38	138.96	114.74	84.87	63.82	49.48	41.58	33.82	28.29	23.29	16.45	13.82	11.58	9.82
39	135.38	111.80	82.69	62.20	48.21	40.52	32.95	27.57	22.69	16.03	13.47	11.29	9.57
40	132.00	109.00	80.63	60.63	47.00	39.50	32.13	26.88	22.13	15.63	13.13	11.00	9.33
41	128.78	106.35	78.66	59.15	45.86	38.58	31.35	26.22	21.60	15.25	12.81	10.74	9.10
42	125.71	103.81	76.79	57.74	44.77	37.62	30.60	25.60	21.08	14.90	12.50	10.48	8.89
43	122.79	101.40	75.00	56.40	43.73	36.75	29.90	25.00	20.50	14.54	12.21	10.24	8.68
44	120.00	99.10	73.30	55.12	42.73	35.91	29.21	24.44	20.12	14.21	11.94	10.00	8.48
45	117.33	96.89	71.67	53.90	41.80	35.12	28.56	23.90	19.67	13.90	11.67	9.78	8.30
46	114.78	94.79	70.11	52.72	40.88	34.35	27.94	23.37	19.24	13.59	11.42	9.57	8.11
47	112.34	92.77	68.62	51.60	40.00	33.62	27.35	22.90	18.83	13.30	11.18	9.37	7.91
48	110.00	90.84	67.20	50.52	39.17	32.92	26.78	22.40	18.44	13.03	10.94	9.17	7.78
49	107.75	88.99	65.82	49.49	38.36	32.25	26.03	21.94	18.07	12.77	10.72	8.98	7.62
50	105.60	87.20	64.50	48.50	37.60	31.60	25.70	21.50	17.70	12.50	10.50	8.80	7.46
51	103.52	85.50	63.24	47.55	36.97	31.00	25.20	21.09	17.36	12.26	10.30	8.63	7.32
52	101.53	83.85	62.02	46.64	36.16	30.39	24.75	20.68	17.02	12.02	10.10	8.47	7.18
53	99.64	82.27	60.86	45.76	35.48	29.82	24.25	20.29	16.70	11.80	9.92	8.31	7.04
54	97.77	80.75	59.73	44.91	34.82	29.26	23.80	19.91	16.40	11.58	9.73	8.15	6.91
55	96.00	79.28	58.64	44.10	34.19	28.73	23.37	19.55	16.10	11.37	9.55	8.00	6.78

Guys. All poles at angles in the line must be properly guyed, using No. 4 B. & S. galvanized iron wire, or two No. 8 wires twisted. All junction poles should also be guyed. Never attach a guy wire to a pole so that it prevents a cross-arm from being removed.

For alternating work, double petticoat insulators are recommended. Pole brackets, except in connection with the tree insulators, should not be used.

Tape should be secured at either end of a joint by a few turns of twine. When looping for lamps, etc., leave coiled sufficient wire, without waste, to reach lamp or building without joints. In cutting arc or incandescent lamps into an existing circuit, use a piece of "rubber-covered" wire. Feeder wires should be strung on the cross-arms above the mains.

For good distribution, arc lamps should not be placed more than 800 feet apart. The lamps may be brought nearer together if a greater degree of illumination is desired.

Primary Wires on Poles. When running more than one circuit of primaries upon the same line of poles the wires of each circuit should be run parallel and on adjacent pins, as shown below, so as to avoid any fluctuation in the lamps due to induction. The lines lettered A and A are for circuit No. 1, and B and B for circuit No. 2, etc.

..............................A
..............................A
..............................B
..............................B

When connecting transformers to 1,000-volt mains a double-pole cut-out is placed in the primary circuit. For 2,000-volt circuits a single-pole cut-out should be placed in each side of the line, thus avoiding any possible short circuit due to an arc being established across the contacts of the double-pole cut-out. This, owing to the greater difference of potential between opposite poles, is liable to occur when the fuses "blow."

INSIDE WIRING.

Approved "Rubber-Covered" Wire should be used exclusively in all interior wiring. Although the Fire Underwriters

allow "Slow Burning" weatherproof wire to be used in dry places when wiring is entirely exposed to view and rigidly supported on porcelain or glass insulators, "Rubber-Covered" wire is always preferable.

The copper conductors, before being rubber covered, should be thoroughly tinned, and the thickness of the rubber covering should conform to the following table:

TABLE V.

Requisite Thickness of Rubber Covering for Wires.

For voltages up to 600:

From No.	18	to No.	16	inclusive,	$\frac{1}{32}$ in.
"	14	to "	8	"	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	1	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

For voltages between 600 and 3,500:

From No. 14 to No.	1	inclusive,	$\frac{3}{32}$ in.	
" 0 to "	500000 c. m.	"	$\frac{3}{32}$ in.	covered by
Larger than	500000 "	"	$\frac{4}{32}$ in.	braid or tape.

"Slow Burning Weatherproof" Wire should have an insulation consisting of two coatings, the inner one to be fireproof in character and the other to be weatherproof. The inner fireproof coating should comprise at least six-tenths of the total thickness of the wall.

The complete covering should be of a thickness not less than that given in the following table:

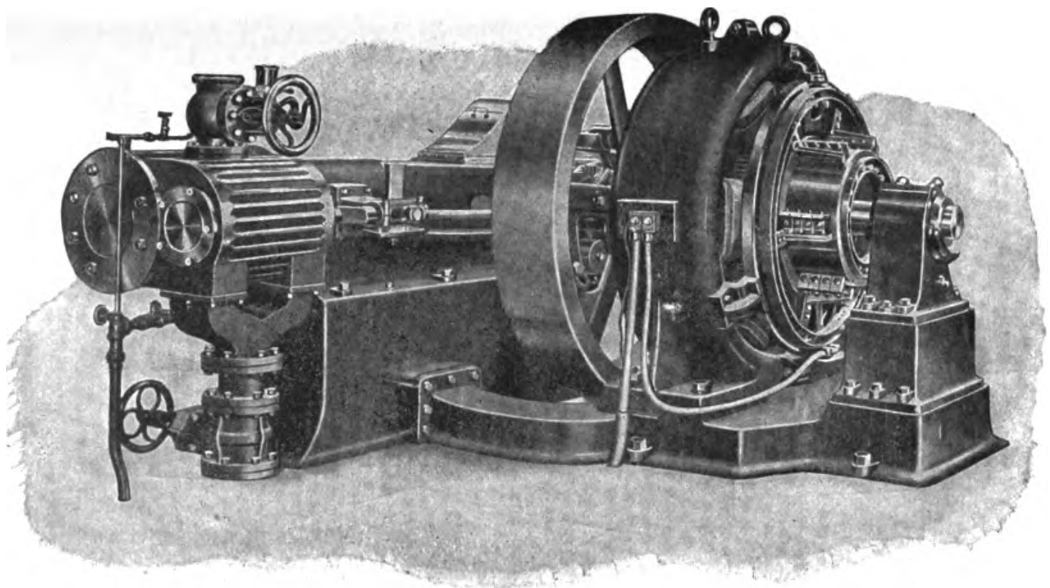
TABLE VI.

Requisite Thickness of Slow Burning Weatherproof Insulation.

From No.	14	to No.	8	inclusive,	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	2	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

"Weatherproof" Wire, for out-door use, should consist of at least three braids thoroughly impregnated with a dense moisture-repellant which should stand a temperature of 180° Fahrenheit without dripping. The thickness should correspond to that of "Slow Burning Weatherproof" and the outer surface should be thoroughly slicked down.

Carrying Capacity of Wires. Table VII gives the safe carrying capacity of wires from No. 18 B. & S. to cables of 2,000,000 circular mils.



100 K.W. ENGINE-TYPE GENERATOR AND AUTOMATIC HIGH-SPEED ENGINE.

Triumph Electric Company.

No wires smaller than No. 14 should be used except for fixture wiring and pendants, in which cases as small as No. 18 may be used.

TABLE VII.

Safe Carrying Capacity of Wires.

Gauge No. B. & S. Diameter Mils. Area Circular Mils. No. Amperes Open Work. No. Amperes Concealed Work. Ohms Per 1000 Ft. Lbs. per 1000 Ft. Bare. Lbs. Per 1000 Ft. Insulated. No. and Size of Wires for Cables.

Gauge No. B. & S.	Diameter, Mils.	Area, Circular Mils.	No. Amperes, Open Work.	No. Amperes, Concealed Work.	Ohms per 1000 Ft.	Lbs. per 1000 Ft. Bare.	Lbs. per 1000 Ft. Insulated.	No. and Size of Wires for Cables.
18...	40	1,624	5	3	6.3880	4.92	18	
17...	45	2 048	6	4	5.0660	6.20	21	
16...	51	2,583	8	6	4.0176	7.82	25	
15...	57	3,257	10	8	3.1860	9.86	31	
14...	64	4,106	16	12	2.5266	12.44	38	
13...	72	5,178	19	14	2.0037	15.68	43	
12...	81	6,530	23	17	1.5890	19.77	48	
11...	91	8,234	27	21	1.2602	24.93	64	
10...	102	10,380	32	25	.99948	31.44	80	
9...	114	13,090	39	29	.79242	39.65	97	
8...	128	16,510	46	33	.62849	49.99	116	
7...	144	20,820	56	39	.49845	63.03	118	
6...	162	26,250	65	45	.39528	79.49	166	
5...	182	33,100	77	53	.31346	100.23	196	
4...	204	41,740	92	63	.24858	126.40	228	
3...	229	52,630	110	75	.19714	159.38	265	
2...	258	66,370	131	88	.15633	200.98	296	
1...	289	83,690	156	105	.12398	253.43	329	
0...	325	105,500	185	125	.09827	319.74	421	
00...	365	133,100	220	150	.07797	402.97	528	
000...	410	167,800	262	181	.06134	508.12	643	
0000...	460	211,600	312	218	.04904	640.73	815	
Cables.	630	300,000	405	273	.03355	932.	Weight of insulations on cables varies for different kinds of work.	37-090
" .	727.3	400,000	503	332	.02516	1242.		37-1039
" .	814.5	500,000	595	390	.02013	1553.		61-0905
" .	891.9	600,000	682	440	.01666	1863.		61-0991
" .	963.9	700,000	765	488	.01438	2174.		61-1071
" .	1030.5	800,000	846	540	.01258	2474.		61-1145
" .	1092.6	900,000	924	585	.01118	2795.		61-1214
" .	1152.	1,000,000	1000	630	.01006	3106.		61-128
" .	1208.7	1 100,000	1075	675	.00915	3416.		61-1343
" .	1262.8	1,200,000	1147	715	.00838	3727.		91-1148
" .	1314.5	1,300,000	1217	755	.00769	4038.		91-1195
" .	1364.	1,400,000	1287	795	.00715	4348.		91-124
" .	1413.5	1,500,000	1356	835	.00667	4658.		91-1285
" .	1458.6	1,600,000	1423	875	.00625	4968.		91-1326
" .	1503.7	1 700,000	1489	910	.00588	5278.		91-1367
" .	1547.7	1,800 000	1554	945	.00556	5588.		127-1195
" .	1571.9	1,900,000	1618	980	.00527	5898.		127-1223
" .	1630.2	2,000,000	1681	1015	.00500	6208.		127-1254

Tie Wires should have an insulation equal to that of the conductors they confine.

Splicing should be done in such manner as to make the wires mechanically and electrically secure without solder; then they should be soldered to insure preservation from corrosion and from consequent heating due to poor contact.

Stranded Wires should have their tips soldered before being fastened under clamps or binding screws. When the stranded wires have a conductivity greater than No. 10 B. & S. copper wire, they should be soldered into lugs. All joints should be soldered in preference to using any kind of splicing device.

Wiring Table. The following examples show the method of using the table on page 40:

1. What size of wire should we use to run 50 16-candle-power lamps of 110 volts, a distance of 150 feet to the center of distribution with the loss of 2 volts?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, which will equal 3,825 ampere feet. Then refer to the columns headed "Actual Volts Lost"; and as we are to have a loss of two volts only, look down the column headed 2 until you come to the nearest corresponding number to 3,825, and we find that 3,900 is the best number to use. Put your pencil on the number 3,900 and follow that horizontal column to the left until you come to the vertical column headed "Size B. & S.," and you find that a No. 4 B. & S. wire will be the proper size to use in this case.

2. What size of wire should we use to carry current for a motor that requires 30 amperes and 220 volts, and is situated 200 feet from the distributing pole, the "drop" in volts not to exceed 2 per cent?

First multiply 30 amperes by 200 feet, as we did in the first example, and we get 6,000 ampere feet. Now look at the upper left-hand corner of the table and you will see a vertical column headed "Volts." Go down this column until you come to 220, and follow the horizontal column to the right until you come to the figure 1.8, which is the nearest we can come to a 2 per cent loss without a greater loss or "drop." Place your pencil on the figure 1.8 and follow down the vertical column of figures until you come to the nearest corresponding figure to 6,000, which we find to be 6,200. Then with your pencil on this figure follow the horizontal column to the left, and we find that a No. 5 B. & S. wire is a proper size to use for the above conditions.

3. Supposing we have occasion to inspect a piece of wiring, and find a dynamo operating 50 16-c. p. 110-volt lamps at a distance of 150 feet, and our wire gauge shows that wire in use is a No. 12 B. & S., at what loss, or "drop," are these lamps being operated?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, and we get 3,825 ampere feet. As we find in use a No. 12 B. & S. wire, we look for the vertical column headed "Size B. & S." and follow it down until we come to 12. With our pencil on the figure 12 we travel along the horizontal line to the right until we come to the nearest corresponding number to 3,825, which we find to be 4,575. Then starting at this number we travel up the vertical column and we find a loss of about 15 actual volts, or, practically, a 12 per cent loss, which would greatly reduce the candle-power or brilliancy of the lamps.

Installation of Wires. All wiring should be kept free from contact with gas, water or other metallic piping, or with any other conductors or conducting material which it may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. In wet places it should be arranged so that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally.

Wires should be run over rather than under pipes upon which moisture is likely to gather, or which by leaking might cause trouble on a circuit. No smaller size than No. 14 B. & S. gauge should ever be used for any lighting or power work, not that it may not be electrically large enough, but on account of its mechanical weakness and liability to be stretched or broken in the ordinary course of usage. Smaller wire may be used for fixture work, if provided with approved rubber insulation.

Wires should never be laid in or come in contact with plaster, cement, or any finish, and should never be fastened by staples, even temporarily, but always supported on porcelain cleats which will separate the wires at least one-half inch from the surface wired over and keep the wires not less than two and one-half

TABLE VIII.

Wiring for Light and Power Circuits.

To find size of wire, multiply current in amperes by single distance and refer to the nearest corresponding number under column of Actual Volts Lost.

VOLTS.	PERCENTAGE OF LOSS.																
2000	1.7	1.5	1.4	1.2	1.1	1.0	0.75	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
1000	3.4	2.9	2.7	2.4	2.2	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
500	6.5	5.7	5.2	4.8	4.3	3.9	2.9	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
220	13.7	12.0	11.0	10.3	9.3	8.3	6.5	4.4	3.9	3.5	3.1	2.7	2.2	1.8	1.4	0.9	0.45
110	—	—	20.0	18.5	17.0	15.4	12.0	8.4	7.6	6.8	6.0	5.2	4.4	3.5	2.7	1.8	0.9
52	—	—	—	—	—	—	22.4	16.1	14.7	13.3	11.8	10.3	8.8	7.1	5.5	3.7	1.9

ACTUAL VOLTS LOST.

*Carrying Capacity, Amperes	Size B. & S.	35	30	27.5	25	22.5	20	15	10	9	8	7	6	5	4	3	2	1
300	0000	345800	296400	271700	247000	222300	197600	148200	98800	88920	79040	69160	59280	49400	39520	29640	19760	9880
245	000	274400	235200	215600	196000	176400	156800	117600	78400	70560	62720	54880	47040	39200	31360	23520	15680	7840
215	00	217525	186450	170912	155375	139837	124300	93225	62150	55935	49720	43505	37290	31075	24860	18645	12430	6215
190	0	172550	147900	135575	123250	110925	98600	73950	49300	44370	39440	34510	29580	24650	19720	14790	9860	4930
160	1	136850	117300	107525	97750	87975	78200	58650	39100	35190	31280	27370	23460	19550	15640	11730	7820	3910
135	2	108500	93000	85250	77500	69750	62000	46500	31000	27900	24800	21700	18600	15500	12400	9300	6200	3100
115	3	86100	73800	67650	61500	55350	49200	36900	24600	22140	19680	17220	14760	12300	9840	7380	4920	2460
100	4	68250	58500	53625	48750	43875	39000	29250	19500	17550	15600	13650	11700	9750	7800	5850	3900	1950
90	5	54250	46500	42625	38750	34875	31000	23250	15500	13950	12400	10850	9300	7750	6200	4650	3100	1550
80	6	43050	36900	33825	30750	27675	24600	18450	12300	11070	9840	8610	7380	6150	4920	3690	2460	1230
60	8	26985	23130	21202	19275	17347	15420	11565	7710	6939	6168	5397	4626	3855	3084	2313	1542	771
40	10	16975	14550	13337	12125	10912	9700	7275	4850	4365	3880	3395	2910	2425	1940	1455	970	485
30	12	10675	9150	8388	7625	6862	6100	4575	3050	2745	2440	2135	1830	1525	1220	915	610	305
22	14	6720	5760	5280	4800	4320	3840	2880	1920	1728	1536	1344	1152	960	768	576	384	192
15	16	4235	3630	3328	3025	2723	2420	1815	1210	1089	968	847	726	605	484	363	242	121

***NOTE. In case a larger loss than any given in the table is required, proceed as follows: Divide the ampere feet by 10, and then refer to column Actual Volts Lost divided by 10, from which we find the size wire as before.**

inches apart. Three-wire cleats may be used when the neutral wire is run in the center and at least two and one-half inches separate the two outside or + and — wires. This style of wiring is intended for low-voltage systems (300 volts or less); and when it is all open work, rubber-covered wire is not necessary, as "weatherproof" wire may be used. Weatherproof wire should not be used in moulding. Wires should not be fished between floors, walls or partitions, or in concealed places, for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with, as this style of work is always more or less uncertain.

Twin wires should never be used, except in conduits or when flexible conductors are necessary; they are always unsafe for light or power circuits on account of the short distance between them.

All wiring should be protected on side walls from mechanical injury. This may be done by putting a substantial boxing about the wires, allowing an air space of one inch around the conductors, closed at the top (the wire passing through bushed holes) and extending about five feet above the floor. Sections of iron-armored conduit may be used, and in most cases are preferable, as they take up but little room and are very rigid.

If, however, iron pipes are used with alternating currents, the two or more wires of a circuit should always be placed in the same conduit. If plain iron pipe be used the insulation of that portion of each wire within the pipe should be reinforced by a tough conduit tubing projecting beyond the iron tubing at both ends about two inches.

When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires should be attached, by their insulating supports, to the under side of wooden strips not less than one-half inch in thickness and not less than three inches wide.

GENERAL FORMULÆ FOR LIGHT AND POWER WIRING.

c. $m.$=circular mils.

d = length of wire, in feet, on one side of **circuit.**

n = number of lamps in multiple.

TABLE IX.

Dimensions and Resistances of Copper Wire.

Gauge. No.	Diam. Mils.	Area, Circ. Mils. B. and S. Gauge.	BARE WIRE. Lbs. per 1000 ft.	BARE WIRE. Lbs. per. Mile.	BARE WIRE. Ft. per Pound.	WEATHERPROOF WIRE. Lbs. per 1000 ft.	WEATHERPROOF WIRE. Lbs. per Mile.	WEATHERPROOF WIRE. Ft. per Pound.	*Safe Carrying Capacity, Cur. in Amp.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.	Area C. M. B. W. G.
0000	460.	211600.	640.73	3383.04	1.56	800	4224.	1.25	312	.04904	.25891	20392.9	206100
000	410.	167800.	508.12	2682.85	1.97	666	3516.	1.50	262	.06184	.32649	16172.1	180600
00	365.	133100.	402.97	2127.66	2.48	500	2640.	2.00	220	.07797	.41168	12825.4	144400
0	325.	105600.	319.74	1688.20	3.13	363	1917.	2.75	185	.09827	.51885	10176.4	115600
1	289.	83690.	253.43	1338.10	3.95	313	1653.	3.20	156	.12398	.65460	8066.0	90000
2	258.	66370.	200.98	1061.17	4.98	250	1320.	4.00	131	.15633	.82543	6396.7	80660
3	229.	52630.	159.38	841.50	6.28	200	1056.	5.00	110	.19714	1.04090	5072.5	67080
4	204.	41740.	126.40	667.38	7.91	144	760.	6.9	92	.24858	1.31248	4022.9	56640
5	182.	33100.	100.23	529.23	9.98	125	660.	8.0	77	.31346	1.65507	3190.2	48400
6	162.	26250.	79.49	419.69	12.58	105	554.	9.5	65	.39528	2.08706	2529.9	41210
7	144.	20820.	63.03	332.82	15.86	87	364.	11.5		.49845	2.63184	2006.2	32400
8	128.	16510.	49.99	263.96	20.00	69	301.	14.5	46	.62849	3.31843	1591.1	27230
9	114.	13090.	39.65	209.35	25.22					.79242	4.18400	1262.0	21900
10	102.	10380.	31.44	165.98	31.81	50	264.	20.0	32	.99948	5.27726	1000.5	17960
11	91.	8234.	24.9	131.65	40.11					1.2602	5.65357	793.56	14400
12	81.	6530.	19.77	104.40	50.58	31	164.	32.0	23	1.5890	8.39001	629.32	11810
13	72.	5178.	15.68	82.792	63.78					2.0037	10.5798	499.06	9025
14	64.	4106.	12.44	65.658	80.42	22	116.	45.0	16	2.5266	13.3405	395.79	6889
15	57.	3257.	9.86	52.069	101.40					3.1860	16.8223	313.87	5184
16	51.	2583.	7.82	41.292	127.87	14	74.	70.0	8	4.0176	21.2130	248.90	4225
17	45.	2048.	6.20	32.746	161.24					5.0660	26.7485	197.39	3364
18	40.	1624.	4.92	25.970	203.31	11	58.	90.0	5	6.3880	33.7285	156.54	2400
19	36.	1288.	3.90	20.594	256.39					8.0555	42.5329	124.14	1764
20	32.	1021.	3.09	16.331	323.32					10.1584	53.6362	98.44	1230

*Safe carrying capacity of exposed wire. Carrying capacity of wire enclosed in moulding is about 40 per cent less. See table on page 37 fifth column.

Approximate weight of weatherproof line wire is 10% less than the weight of underwriters' wire as given above.

c = current in amperes per lamp.

v = volts lost in lines.

r = resistance per foot of wire to be used.

10.8 ohms resistance of one foot of commercial copper wire having a diameter of one mil and a temperature of 75° Fahrenheit.

It is an easy matter to find any of the above values by the following formulæ:

$$c.m. = \frac{10.8 \times 2d \times n \times c}{v}$$

$$v = \frac{10.8 \times 2d \times n \times c}{c.m.} \qquad c = \frac{c.m. \times v}{10.8 \times 2d \times n}$$

$$n = \frac{c.m \times v}{10.8 \times 2d \times c} \qquad 2d = \frac{c.m. \times v}{10.8 \times c \times n}$$

$$r = \frac{v}{n \times c \times 2d}$$

$$v = n \times c \times 2d \times r \qquad c = \frac{v}{2d \times n \times r}$$

$$n = \frac{v}{c \times 2d \times r} \qquad 2d = \frac{v}{n \times c \times r}$$

Arc Light Wiring. All wiring in buildings for constant-current series arc lighting should be with approved rubber-covered wire, and the circuit arranged to enter and leave the building through an approved double-contact service switch, which means a switch mounted on a non-combustible, non-absorptive insulating base and capable of closing the main circuit and disconnecting the branch wires when turned "off." This switch must be so constructed that it will be automatic in action, not stopping between points when started, must prevent an arc between points under all circumstances, and must indicate, upon inspection, whether the current is "on" or "off." Such a switch is necessary to cut the high voltage completely out of the building by firemen in case of fire or when it becomes necessary to make any changes in the lamps or wiring.

This class of wiring should never be concealed or encased except when requested by the Electrical Inspector, and should always be rigidly supported on porcelain or glass insulators which will separate the wiring at least one inch from the surface wired over, and which must be kept at least four inches from each other on all voltages up to 750, and eight inches apart when the voltages exceed 750. No wires carrying a voltage of over 3,500 should be carried into or over any buildings except central stations and sub-stations. All arc light wiring should be protected on side walls and when crossing floor timbers where wires are liable to injury. In mill-construction buildings, arc wires of No. 8 and larger, where not liable to be disturbed, may be separated six inches for voltages up to 750, and ten inches for voltages above 750; may run from timber to timber, not breaking round; and may be supported at each timber only. In running along beams or walls and ceilings they should be supported at intervals not exceeding four and one-half feet.

SPECIAL WIRING.

Special wiring for damp places such as breweries, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture or acid or other fumes likely to injure the wires or their insulation, should be done with approved rubber-covered wire, and rigidly supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over, and which must be kept apart at least two and one-half inches. The wire in such damp places should contain no splices, as it is almost impossible to tape a splice that will prevent acid fumes from getting at the copper surface.

Moulding Work should always be done with approved rubber covered wire to prevent leakage should the moulding become damp.

This class of work should never be done in concealed or damp places, for fear that water may soak into the wood and cause leakage of current between the wires, burning the wood and starting a fire. The action of the current in a case like this is to convert the wood very gradually into charcoal, then dry the water out and ignite the charcoal thus formed. Great care should be ob-

served in driving nails into moulding, to avoid puncturing the insulation and possibly grounding the circuit in a way that not only might be difficult to locate, but might cause a concealed fire back of the plastering or wood work to which the moulding is attached.

Moulding should be of hard wood and made of two pieces, a backing and capping, so constructed as to thoroughly encase the wire. It should provide a one-half inch tongue between the conductors and a solid backing, which under the grooves should be not less than three-eighths of an inch in thickness and able to give suitable protection from abrasion.

Concealed Wiring or that which is to be run between walls and floors and their joists, should always be done with approved rubber-covered wire, and should be rigidly supported on porcelain or glass insulators which will separate the wires at least

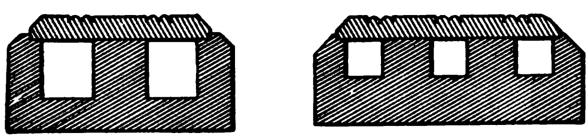


Fig. 10.

Samples of approved moulding when filled and covered with at least two coats of waterproof paint.

one inch from the surface wired over. The wires should be kept at least ten inches apart, and where it is possible should be run singly on separate timbers or joists. The insulators should be placed not farther than four feet apart in any case, and where there is any liability of the wires coming in contact with anything else, due to a possible sagging, the supports should be placed much closer together. In some cases where it is impossible to rigidly support the wiring on porcelain or glass insulators in concealed places, the wires, if not exposed to moisture, may be fished on the loop system if encased throughout in approved continuous flexible tubing or conduit. Fishing under floors or between walls is done by boring holes at suitable distances apart and pushing a flat spring wire from one hole toward the other and catching it with a wire hook. The flexible conduit and wires may then be pulled into place.

Although this fished work may be passed when the surrounding conditions are, at the time of inspection, perfectly satisfactory, it should be avoided, as trouble will arise in this class of work sooner than in any other, when all conditions are equal.

Insulated Metal Conduits — (Specifications). The metal covering or pipe should be of sufficient thickness to resist penetration by nails, etc., or the same thickness as ordinary gas pipe of the same size.

It should not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

The insulating lining should be firmly attached to the pipe, and should not crack or break when a length of conduit is uniformly bent at a temperature of 212 degrees Fahrenheit, to an angle of 90 degrees, with a curve having a radius of 15 inches, for pipes of 1 inch or less, or a radius of fifteen times the diameter of the pipe for larger sizes.

The insulating lining should not soften injuriously at a temperature below 212 degrees Fahrenheit, and should leave water in which it has been boiled, practically neutral.

The insulating lining should be at least one-thirty-second of an inch in thickness; and the materials of which it is composed should be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing in and out of some long lengths of conductors.

The insulating lining should not be mechanically weak after three days' submersion in water, and, when removed from the pipe entire, should not absorb more than ten per cent of its weight of water during 100 hours of submersion.

All elbows should be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow should not be less than three and one-half inches.

There should not be more than the equivalent of four quarter bends from outlet to outlet, the bends at outlets not being counted.

Each length of conduit, whether insulated or uninsulated, should have the maker's name or initials stamped in the metal or

attached to it in some satisfactory manner, so that it may be readily seen, thus rendering it possible to place the responsibility for pieces not up to standard.

Uninsulated Metal Conduits or plain iron or steel pipes may be used instead of the insulated metal conduits, if made equally as strong and thick as the ordinary form of gas pipe of the same size, provided their interior surfaces are smooth and free from burrs. To prevent oxidation, the pipe should be galvanized, or the inner surfaces coated or enameled with some substance which will not soften so as to become sticky and prevent the wire from being withdrawn from the pipe. Elbows must be made for the purpose, and not bent from lengths of pipe. The radius of curves and number of bends from outlet to outlet should be the same as given under Insulated Metal Conduits. This bare iron or steel pipe should never contain any but a special extra insulated wire as hereinafter described:

Conduit Wire for Insulated Metal Conduits, whether single or twin conductors, should be standard rubber-covered wire as described on page 35; and where concentric wire is used in insulated metal conduits, it should have a braided covering between the outer conductor and the insulation of the inner conductor, and in addition should comply with and be able to withstand the test of standard rubber-covered wire.

Conduit Wire for Uninsulated Metal Conduits should not only have a standard rubber insulation as required for Insulated Metal Conduits, but in addition should have a second outer fibrous covering at least one-thirty-second inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit. When concentric conductors are to be used in uninsulated metal conduits, they not only should comply with the requirements when used in insulated metal conduits, but, in addition, should have a second outer fibrous covering at least one-thirty-second of an inch in thickness and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

Interior Conduit Installation. All conduits should be continuous from one junction box to another or to fixtures, and the

conduit tube should properly enter all fittings, otherwise the conductors are not perfectly protected, and water is much more liable to gain an entrance into the conduit. No conduit with an inside diameter of less than five-eighths inch should be used.

The entire conduit system for a building should be completely installed before a single wire is drawn in; and all ends of conduits should extend at least one-half inch beyond the finished surface of walls or ceilings, except that, if the end is threaded and a coupling screwed on, the conduit may be left flush with the surface, and the coupling may be removed when work on the building is completed.

After all conductors have been drawn or pushed in, all outlets should be plugged up with special wood or fibrous plugs made in parts to fit around the wire, and the outlet then sealed with a good compound to keep out all moisture. All joints should be made air-tight and moisture-proof.

The metal of every conduit system should be effectually and permanently grounded. The conduit is likely to be more or less grounded, and a positive ground is necessary for the same reason that a positive ground is required for generator frames when it is impossible to insulate them perfectly.

Conduit Wiring. The reason why standard rubber covered wire, and not weatherproof, should be used in conduits, is that the best possible insulation is desirable for this class of work, as the insulating lining of the conduit may be defective in places, and there is a possibility of dampness getting into the conduit.

No wires should be drawn in until all mechanical work on the building is done.

Wires of different circuits should not be drawn in the same conduit.

For alternating systems, the two or more wires of a circuit should be drawn in the same conduit, in order to avoid trouble from inductive losses, which, under certain conditions, would cause a heating of the iron conduit to a dangerous degree. This trouble from induction becomes very much less if the wires are in the same conduit; less still, if the wires are twisted together; and disappears almost entirely if concentric wire is used.

Even in direct-current work it is advisable to place the two wires of a circuit in the same conduit, as in so doing the direct current may be changed for the alternating current without the necessity of rewiring, which would be necessary if only a single wire were placed in a conduit.

Fixtures, when supported from the gas piping of a building, should be insulated from the gas-pipe system by means of approved insulating joints placed as close as possible to the ceiling, and the wires near the gas pipe above the insulating joint should be protected from possible contact by the use of porcelain tubes.

All burrs or fins should be removed from the fixtures before the wires are drawn in. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

In combination fixtures, where the wiring is concealed between the inside pipe and outer casing, the space between pipe and casing should be at least a quarter of an inch to allow plenty of room for the insulation of the wires without jamming.

Fixtures should be tested for "contacts" between conductors and fixtures, for "short circuits" and for ground connections, before being connected to the supply conductors.

Ceiling blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate should be surrounded by porcelain tubes.

Rosettes. These fittings should not be located where inflammable flyings or dust will accumulate on them. Bases should be high enough to keep the wires and terminals at least one-half inch from the surface to which the rosette is attached.

Terminals with a turned up lug to hold the wire or cord should be used, and in no case must the wire be cut or injured. Fused rosettes are not advised for use where cords can be properly protected by line cut-outs. If fused rosettes are used, the next fuses back should not be over 25 amperes capacity.

Fixture Wiring should be done with fixture wire, which has a solid insulation with a slow-burning, tough, outer covering, the whole at least one-thirty-second of an inch in thickness, and having an insulation resistance between conductors, and between

either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at 70 degrees Fahrenheit, and after three minutes' electrification with 550 volts.

Although No. 18 (B. & S. gauge) is allowable in fixture work, it is never advisable to use smaller than No. 16, for mechanical reasons. Supply conductors, and especially the splices to fixture wires, should be kept clear of the grounded part of gas pipes, and where shells are used the latter should have area enough to prevent pressing the wires against the gas pipe when finally in place. Where fixtures are wired on the outside, it is advisable to use cord for attaching the wires to the fixture, and not short bits of wire, as the latter might produce a short circuit or ground.

Flexible Cord should be made of a number of copper strands; no single strand should be larger than No. 26 or smaller than No. 30 (B. & S. gauge), and each conductor should be covered by an approved insulation and be protected from mechanical injury by a tough, braided, outer covering. When used for pendant lamps it should hang freely in air and be so placed that there is no chance of its coming in contact with anything excepting the lamp socket to which it is attached and the rosette from which it hangs. Each stranded conductor should have a carrying capacity equivalent to not less than a No. 18 (B. & S. gauge) wire. The covering of the stranded wires for flexible cord should first have a tight, close wind of fine cotton, which is intended to prevent any broken strand from piercing the insulation and causing a short circuit or ground. Secondly, it should have a solid waterproof insulation at least one-thirty-second of an inch thick, and should show an insulation resistance of 50 megohms per mile throughout two weeks' submersion in water at 70 degrees Fahrenheit. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out.

Flexible cord should not be used as a support for clusters, as it is not strong enough, and it should never be used for anything other than pendants, wiring of fixtures and portable lamps. portable motors, or small, light electrical apparatus.

Flexible cord should never be used in show windows, as a

defective piece might cause a short circuit and set fire to flimsy material or decorations. Many fires have been caused by the use of flexible cord in show windows, where handkerchiefs, decorations, etc., have been pinned to the cord. When the current is "turned on" short circuits are caused by the pins, and a fire is the result.

Insulating bushings should be used where cords enter lamp sockets and desk stand lamps.

Flexible cord should be so suspended that the entire weight of the socket, lamp and shade will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws. It is good practice always to solder the ends of flexible cords which are going under binding screws, as it holds the strands together and prevents the pressure of the screws from forcing the strands from under them and against the shell of the socket, causing a grounded shell or short circuit.

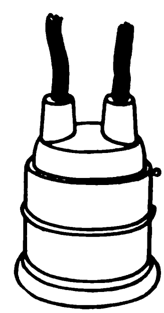


Fig. 11.
Waterproof keyless socket, to be used in dye houses or damp places.

Where it becomes necessary to solder a great number of ends, as may be required when wiring a factory, use a small pot of melted solder and dip the ends of the wire, which have all been previously cut to the proper length.

Standard Lamp Sockets should be plainly marked 50 candle-power, 250 volts, and with either the manufacturer's name or registered trade mark. The inside of the shell of the socket should have an insulating lining which should absolutely prevent the shell from becoming part of the circuit, even though a wire or strand inside the socket should become loose or come out from under a binding screw. This insulating lining should be at least one-thirty-second of an inch thick and of a tough and tenacious material.

Special Lamp Sockets. In rooms where inflammable gases may exist, both the socket and lamp should be enclosed in a vapor-tight globe, supported on a pipe-hanger, and wired with "Rubber-

Covered" wire soldered directly to the circuit. No fuses or switches of any sort should be used in such cases, as the slightest arc might produce dangerous explosions or fires. See Fig. 11.

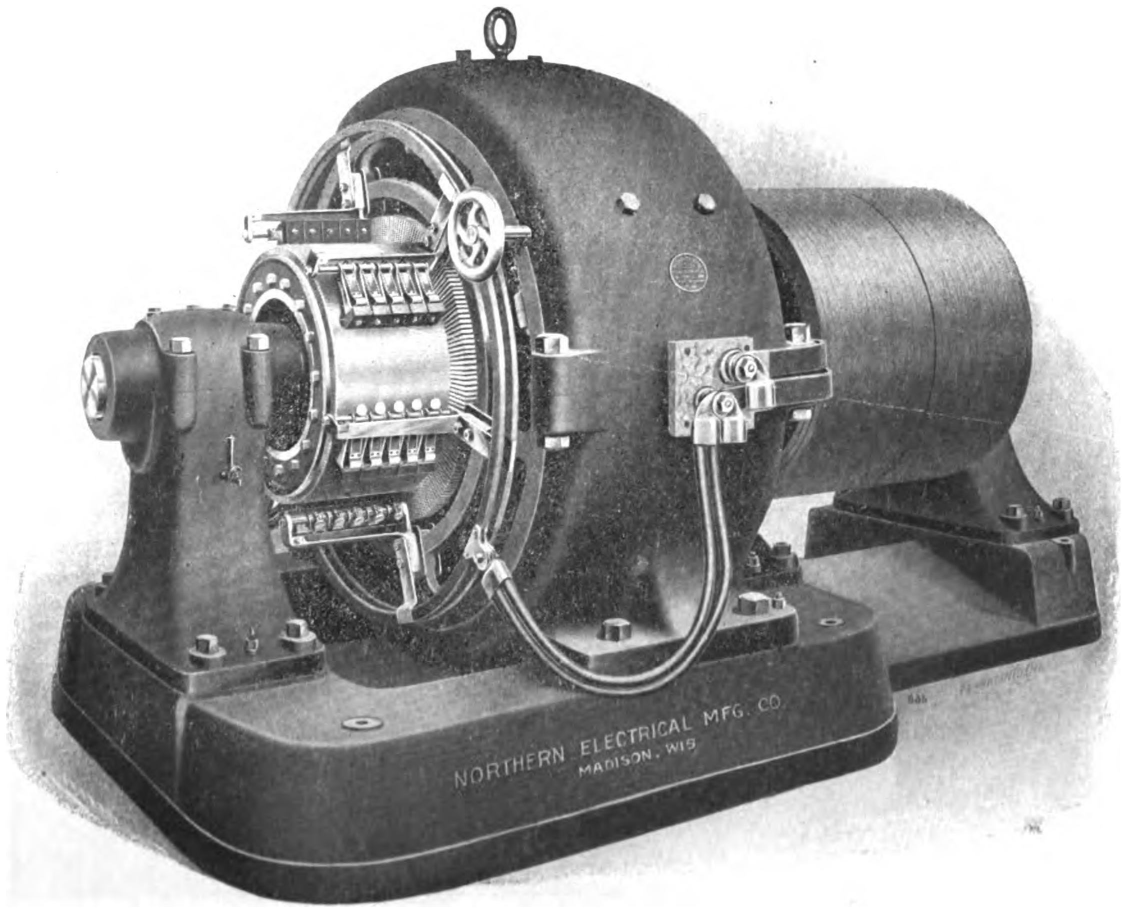
In damp or wet places, such as dye houses, breweries, etc., a waterproof socket such as shown on page 51 should be used. Waterproof sockets should be hung by separate stranded rubber-covered wires, not smaller than No. 14 (B. & S.). These wires should be soldered direct to the circuit wires, but supported independently of them. All sockets for the above conditions should be keyless.

Stranded Wires in every case should be soldered together before being clamped under binding screws, and when they have a conductivity greater than No. 10 (B. & S.) copper wire they should be soldered into lugs. Stranded wires if not thus stiffened before being clamped under binding posts, are liable to be pressed out or easily worked loose, making a poor contact, which causes heating, a possibility of arcing or a complete burn out, or fusing of the wire at this point.

Bushings. All wires should be protected when passing through walls, partitions or floors, by non-combustible, non-absorptive insulating tubes, such as glass or porcelain. Each bushing should be long enough to go clear through and allow a projection of at least a quarter of an inch on both ends. Bushings should be long enough to bush the entire length of the hole in one continuous piece; or else the hole should first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe, and the tube then should have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

Automatic Cut-outs such as circuit breakers and fuses should be placed on all service wires as near as possible to the point where they enter the building, on the inside of the walls, and arranged to cut off the entire current from the building.

The cut-out or circuit breaker should always be the first thing that the service wires are connected to after entering the building; the switch next, and then the other fixtures or devices in their order. This arrangement is made so that the cut-out or



BELTED GENERATOR.
Ring Type, Three Bearing, Six Pole.

circuit breaker will protect all wiring in the building, and the opening of the switch will disconnect all the wiring.

These automatic cut-outs should not, however, be placed in the immediate vicinity of easily ignitible stuff, nor where exposed to inflammable gases or dust, or to flyings of combustible material, as the arcing produced whenever they break the circuit might cause a fire or explosion. When they are exposed to dampness they should be inclosed in a waterproof box or mounted on porcelain knobs. All cut-outs and circuit breakers should be supported on bases of non-combustible, non-absorptive insulating material. Cut-outs should be provided with covers when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any ignitible substance.

Cut-outs should operate successfully under the most severe conditions they are liable to meet with in practice, on short circuits, with fuses rated at 50 per cent above, and with a voltage 25 per cent above, the current and voltage for which they are designed. Circuit breakers should also be designed to operate successfully under the severe conditions liable to be met with in practice, or at 50 per cent above the current and with a voltage of 25 per cent above that for which they are designed. All cut-outs and circuit breakers should be plainly marked, and where it will always be visible, with the name of the maker as well as the current and voltage for which the device is designed.

Cut-outs or circuit breakers should be placed at every point where a change is made in the size of wire, unless such a device in the larger wire will protect the smaller. They should never be placed in canopies or shells of fixtures, but should be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring a current of more than six amperes, should be dependent upon one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction, in case extra large or special chandeliers are to be used. Fused rosettes, when used with flexible cord pendants, are considered as equal to a cut-out. Fuses for cut-outs should not have a capacity to exceed the carrying capacity of the wire; and where circuit breakers are used they should not be set more

than 30 per cent above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

Circuit breakers open at exactly the current they are set for, and instantly; therefore it is necessary to get them considerably above the ordinary amount of current required, to keep them from constantly opening on slight fluctuations. When this is the case a double-pole fusible cut-out should be added to protect the wire from a heavy, steady current, which may be maintained just below the opening point of the circuit breaker. The fuse requires a little time to heat, and therefore would not blow out with a momentary rise of current which might open the circuit breaker if set as low as necessary to protect the wire, which may be of a size only large enough for the figured amount of current under ordinary conditions of operation. If, however, in the case of motor wiring, the size of wire is 50 per cent above the figured size for the motor's average current, as it should be, then the introduction of a fusible cut-out in addition to the circuit breaker is unnecessary.

Insulating Joints should be made entirely of material that will resist the action of illuminating gases, and that will not give way or soften under the heat of an ordinary gas flame, or leak under a moderate pressure.

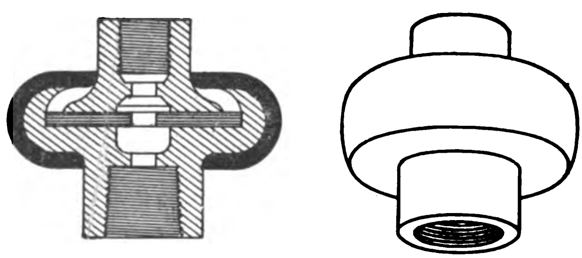


Fig. 12.
The Macallen Insulating Joint.

They should be so arranged that a deposit of moisture will not destroy the insulating effect, and should have an insulation resistance of at least 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

Insulating joints should not contain any soft rubber in their composition. The insulating material should be of some hard and durable material, such as mica. See Fig. 12.

Insulation Resistance. The wiring in any building should test free from grounds, *i. e.,* the complete installation should have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following:

Up to—	
5 amperes	4,000,000
10 amperes	2,000,000
25 amperes	800,000
50 amperes	400,000
100 amperes	200,000
200 amperes	100,000
400 amperes	50,000
800 amperes	25,000
1,600 amperes	12,500

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles and electroliers, etc., are connected, one-half of the above will be required.

Knife Switches. Switches should be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

Knife switches should always be installed so that the handle will be up when the circuit is closed, so that gravity will tend to open rather than close the switch. They should never be single-pole except when the circuit which they control is carrying not more than six 16-candle-power lamps or their equivalent.

Double-pole switches are always preferable to single-pole, as they absolutely disconnect the part of the circuit out of use.

Flush Switches. Where gangs of flush switches are used, whether with conduit systems or not, the switches should be enclosed in boxes constructed of, or lined with, fire-resisting material.

Where two or more switches are placed under one plate, the box should have a separate compartment for each switch. No push buttons for bells, gas lighting circuits, or the like, should be placed in the same wall plates with switches controlling electric light or power wiring.

Snap Switches, like knife switches, should always be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and should have carrying capacity sufficient to prevent undue heating.

When used for service switches they should indicate at sight whether the current is "on" or "off." Indicating switches should be used for all work, to prevent mistakes and possible accidents. The fact that lights do not burn or the motor does not run is not necessarily a sure sign that the current is off.

Every switch, like every piece of electrical apparatus, should be plainly marked, where it is always visible, with the maker's name and the current and voltage for which it is designed.

On constant-potential systems, these switches, like knife switches, should operate successfully at 50 per cent overload in amperes with 25 per cent excess voltage, under the most severe conditions they are likely to meet with in practice. They should have a firm contact, should make and break readily, and not stop when motion has once been imparted to the handle. When this style of switch is used for constant-current systems, they should close the main circuit and disconnect the branch wires when turned "off;" should be so constructed that they will be automatic in action, not stopping between points when started; and should prevent an arc between the points under all circumstances. They should also indicate at sight whether the current is "on" or "off."

Incandescent Lamps. Table X is compiled from a series of careful tests on a number of incandescent lamps taken from a large stock at random.

Poor regulation of voltage results in more trouble with incandescent lamps and their users than any other fault in electric lighting service.

Some men act on the theory that so long as the life of a lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased.

Excessive voltage is thus a double error—it decreases the

TABLE X.
Incandescent Lamp Data.

VOLTS.	C. P.	Amp.	Watts Per Lamp.	Watts Per C. P.	Hot Res.
52	10	.67	35	3.50	77.61
"	16	1.08	56	"	48.14
"	20	1.34	70	"	38.80
"	24	1.62	84	"	32.09
"	32	2.15	112	"	24.18
"	50	3.36	175	"	15.47
"	100	6.73	350	"	7.72
"	150	10.09	525	"	5.15
104	10	.34	35	3.50	305.88
"	16	.54	56	"	192.59
"	20	.67	70	"	185.22
"	24	.81	84	"	128.39
"	32	1.08	112	"	96.29
"	50	1.68	175	"	61.90
"	100	3.36	350	"	30.95
"	150	5.05	525	"	20.59
110	10	.32	35	3.50	343.75
"	16	.51	56	"	215.68
"	20	.64	70	"	171.87
"	24	.76	84	"	144.73
"	32	1.02	112	"	107.84
"	50	1.59	175	"	69.18
"	100	3.18	350	"	34.59
"	150	4.77	525	"	23.06
220	16	.291	64	4.00	756.01
"	32	.582	128	"	379.31

total light of the lamps, and increases the power consumed. If increased light is needed, 20-candle-power lamps should be installed instead of raising the pressure. Their first cost is the same as 16-candle-power lamps; they take but little more current than 16-candle-power lamps operated at high voltage and give greater average light.

Increased pressure also decreases the commercial life of the lamp, and this decrease is at a far more rapid rate than the increase of pressure, as shown in the following table. This table

shows the decrease in life of standard 3.1-watt lamps due to increase of normal voltage.

Per Cent of Normal Voltage.	Life Factor.
100	1.000
101	.818
102	.681
103	.562
104	.452
105	.374
106	.310

From this table it is seen that 3 per cent increase of voltage halves the life of a lamp, while 6 per cent increase reduces the life by two thirds.

Intensity or Brilliancy. The average brilliancy of illumination required will depend on the use to which the light is put. A dim light that would be very satisfactory for a church would be wholly inadequate for a library and equally unsuitable for a ballroom.

The illumination given by one candle at a distance of one foot is called the "candle-foot" and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16-candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming the 16-candle-power lamp as the standard, it is generally found that two 16-candle-power lamps per 100 square feet of floor space give good illumination, three very bright and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination" and producing a "glaring intensity" which should be avoided as carefully as too little intensity of illumination.

Distribution concerns the arrangement of the various sources of light and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points in contrast with the general illumination."

The Arrangement of the Lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings and large rooms, excellent effects are obtained by dividing the ceilings into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and on the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the walls near the ceiling.

For the illumination of show windows and for display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in comparison with an equivalent number of 16-candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16-candle-power lamps. For example, sixteen 64-candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16-candle-power lamps distributed over the same area. High candle-power lamps are useful chiefly when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

The Relative Value of the Arc and Incandescent Systems of Lighting is frequently difficult to determine. Incandescent

TABLE XI.

Tested Fuse Wire.

CHASE-SHAWMUT Co.,
Boston.

Carrying Capacity. Amperes.	Standard Length. Inches.	Diameter in Mils.	Feet Per Pound.
¼	1½	10	2,700
½	1½	17	950
1	1½	20	670
1½	1½	23	510
2	1½	25	430
3	1½	27	370
4	1½	30	300
5	2	35	812
6	2	38	504
7	2	44	021
8	2	47	120
9	2	54	93
10	2	58	80
12	3	62	70
14	3	68	60
15	3	70	52
16	3	73	49
18	3	78	43
20	4	86	36
25	4	90	32
30	4	100	26
35	4	110	22
40	4	122	18
45	4	126	17
50	4	147	12.5
60	5	160	10.3
70	5	172	9.0
75	5	178	8.3
80	5	190	7.5
90	5	198	6.7
100	5	220	5.5

lamps have the advantage that they can be distributed so as to avoid the shadows necessarily cast by one single source of light. Arc lamps used indoors with ground or opal globes cutting off half the light, have an efficiency not greater than two or three times that of an incandescent lamp. Nine 50-watt, 16-candle-power lamps consume the same power as one full 450-watt arc lamp. It has been found that unless an area is so large as to require 200 or 300 incandescent lights distributed over it, arc lamps requiring equal total power will not light the area with so uniform a brilliancy.

Fuses should have contact surfaces or tips of harder metal, having perfect electrical connection with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps or other devices provided for holding the fuse.

Fuses should be stamped with about 80 per cent of the maximum current they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

With naked open fuses of ordinary shapes and not over 500 amperes capacity, the maximum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

The following table shows the minimum break distance, and the separation of the nearest metal parts of opposite polarity, for open-link fuses when mounted on slate or marble bases, for different voltages and different currents:

	Separation of nearest metal parts of opposite polarity.	Minimum break distance.
125 VOLTS OR LESS.		
10 amperes or less	¾ inch	¾ inch
11—100 amperes	1 inch	¾ inch
101—300 amperes	1 inch	1 inch
125 TO 250 VOLTS.		
10 amperes or less	1½ inch	1¼ inch
11—100 amperes	1¾ inch	1¼ inch
101—300 amperes	2 inch	1½ inch

Fuse Terminals should be stamped with the maker's name or initials, or some known trade-mark.

Fuse Wire. Table XI shows the sizes of fuse wire and the approximate current-carrying capacity of each size.

Fuses have been known to blow out simply from the heat due to poor contact when nowhere near their current-carrying capacity had been reached. They should be so put up and protected that nothing will tend to rupture them except an excessive flow of current. No fuse of the larger sizes ever blew out without causing a greater or less fire risk.

Fuses blow out or melt from excessive heat, and nothing else, and are therefore not as instantaneous in their action as a circuit breaker, which is constantly cared for and kept clean. Central stations or large isolated plants subject to greatly varying loads should have their lines and generators protected by both fuses and magnetic circuit breakers as a double protection against excessive current.

The lengths of fuses and distances between terminals are important points to be considered in the proper installation of these electrical "safety valves." No fuse block should have its terminal screws nearer together than one inch on 50 or 100-volt circuits, and one inch additional space should always be allowed between terminals for every 100 volts in excess of this allowance. For example, 200-volt circuits should have their fuse terminals 2 inches apart, 300-volt 3 inches, and 500-volt 5 inches. This rule will prevent the burning of the terminals on all occasions of rupture from maximum current, and this maximum current means a "short circuit." Good contact is absolutely essential in the installation and maintenance of fuses. See that the copper tips to all fuses are well soldered to the fuse wire, and furthermore see that the binding screw or nut is firmly set up against this copper tip when the fuse is placed in circuit; a 100-ampere fuse can be readily "blown" by 25 amperes if the above precautions are not carried out. Poor contact in every case can cause a heating beyond the carrying capacity of the largest fuses. On the other hand, much damage can be done by using too short fuses and too large terminals, as the radiation of heat from the short piece of fuse wire to the heavy metal terminals and set screws or nuts can very easily raise the current-carrying capacity

of a fuse designed to carry 50 amperes to 100 amperes, or even more. All open-link fuses should be placed in cut-out cabinets when possible.

Cut-out Cabinets should be so constructed, and cut-outs so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box may be made of marble, slate or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust tight, and it should be hung on strong hinges and held closed by a strong hook or catch. If the box is wood the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on and firmly secured in place by shellac and tacks. The wires should enter through holes bushed with porcelain bushings, the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to bind up the wire, if necessary), so as to keep out the dust.

The Enclosed Fuse, or "Cartridge Fuse" (see Fig. 13), consists of a fusible strip or wire placed inside of a tubular holding jacket filled with porous or powdered insulating material through which the fuse wire is suspended from end to end and which surrounds the fuse wire. The wire, tube and filling are made into one complete, self-contained device with brass or copper terminals or ferrules at each end, the fuse wire being soldered

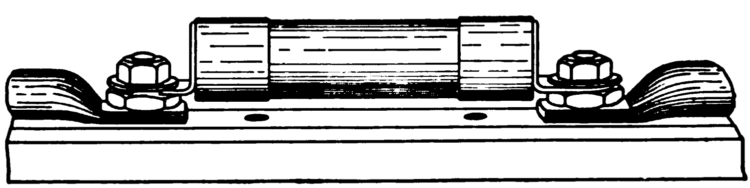


Fig. 13.
Enclosed Fuse.

to the inside of the ferrules. When an inclosed fuse "blows" by excess current or short circuit the gases resulting are taken up by the filling, the explosive tendency is reduced and flashing and arcing are eliminated.

Incandescent Lamps in Series Circuits should be wired with

TABLE XII.

Dimensions of Enclosed Fuses.

By Joseph Sachs.

VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.
	1-8	2 3/16	3/8	1		1-10	4 5/8	3/8	3		1-12	5 3/4	1/2	4 1/2
	10-15	2 11/16	3/8	1		12-25	5 1/4	1/2	3 1/4		15-30	5 3/4	5/8	4 1/2
	20-30	3 3/16	1/2	1 1/4		30-50	5 3/4	3/4	3 1/2		35-50	6 1/4	7/8	5
	35-50	3 3/4	3/4	1 1/2		60-100	6 1/4	1	3 1/2		60-75	6 5/16	1 1/8	5 1/2
220	60-100	4 1/8	7/8	1 1/2	**500**	125-150	6 1/4	1 1/4	3 5/8	**2,500**	80-100	6 5/16	1 1/4	5 1/2
	125-150	4 1/8	1	1 3/4		175-225	6 7/16	1 1/2	3 3/4					
	175-225	4 11/16	1 1/4	2 1/2		250-400	6 5/8	2	3 7/8					
	250-400	4 13/16	1 1/2	2 1/2		500-600	10	2 1/2	4					
	500-600	6 3/16	2	2 1/2										
	1/2-12	15 1/8	3/4	13		1/2-12	24	3/4	18					
5,000	15-30	15 1/8	1	13	**10,000**	15-30	24	1	18	**20,000**	1/4-10	30	1	24
	35-50	18 1/8	1 1/8	14										

the same precaution as for series arc lighting and each lamp should be provided with an automatic cut-off.

Each lamp should be suspended from an approved hanger board by means of a rigid tube, to prevent the wires from constant swinging.

No electro-magnetic device for switches and no system of multiple, series, or series-multiple lighting in this class of work should be used. Under no circumstances should incandescent lamps in series circuits be attached to gas fixtures, as the high voltage necessarily employed in this class of lighting should be kept as far as possible from gas piping, which is so thoroughly grounded or likely to be.

When incandescent lamps are used for decorative purposes, as in the use of miniature colored lamps, and it is necessary to run two or more in series, permission should always be secured, in writing, from the Inspection Department having jurisdiction.

Arc Lamps should be carefully isolated from inflammable material, should be provided at all times with a glass globe surrounding the arc and securely fastened upon a closed base. No broken or cracked globes should be used, as they are designed to prevent hot bits of carbon from falling to the floor should they fall from the carbon holder. All globes for inside work should be covered with a wire netting having a mesh not exceeding one and one-quarter inches, to retain the pieces of the globe in position should the latter become broken from any cause. A globe thus broken should be replaced at once. When arc lamps are used in rooms containing readily inflammable material they should be provided with approved spark arresters, which should be made to fit so closely to the upper orifice of the globe that it would be impossible for any sparks thrown off by the carbons to escape. It is safer to use plain carbons and not copper-plated ones in such rooms, or better still, an enclosed arc lamp, one having its carbons enclosed in a practically tight glass globe which is inside the outer globe. Where hanger-boards are not used arc lamps should be hung from insulating supports other than their conductors.

All arc lamps should be provided with reliable stops to prevent carbons from falling out in case the clamps become loose,

and all exposed parts should be carefully insulated from the circuit. Each lamp for constant-current systems should be provided with an approved hand switch, and also an automatic switch that will shunt the current around the carbons, so that the lamp will thus cut itself out of circuit should the carbons fail to feed properly. If the hand switch is placed anywhere except on the lamp itself, it should comply in every respect with the requirements for switches on hanger-boards as described under the latter heading.

Arc Light Wiring. All wiring for high-potential arc lighting circuits should be done with "Rubber-Covered" wire. The wires should be arranged to enter and leave the building through an approved double-contact service switch, which should close the main circuit and disconnect the wires in the building when turned "off." These switches should be so constructed that they will be automatic in their action, not stopping between points when started, and preventing arcing between points under any circumstances, and should indicate plainly whether the current is "on" or "off." Never use snap switches for arc lighting circuits. All arc light wiring of this class should be in plain sight and never enclosed except when required, and should be supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over. The wires should be kept rigidly at least eight inches apart, except of course within the lamp, hanger-board, or cut-out box or switch. On side walls the wiring should be protected from mechanical injury by a substantial boxing retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet above the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires should be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

Arc Lamps on Low-Potential Circuits should have a cut-out for each lamp or series of lamps. The branch conductors for such lamps should have a carrying capacity about 50 per cent in excess of the normal current required by the lamp or lamps, to

provide for the extra current necessary when the lamps are started, or, should a carbon become stuck, to prevent over-fusing the wires. If any resistance coils are necessary for adjustment or regulation, they should be enclosed in non-combustible material and be treated as sources of heat; it is preferable that such resistance coils be placed within the metal framework of the lamp itself. Incandescent lamps should never be used for resistance devices. These lamps should be provided with globes and spark arresters, as in the case of arc lamps on high-potential series circuits, except when the enclosed arc lamps are used.

Economy Coils, or compensator coils, for arc lamps should be mounted on glass or porcelain, allowing an air space of at least one inch between frame and support, and in general should be treated like sources of heat.

Hanger-Boards should be so constructed that all wires and current-carrying devices thereon will be exposed to view and thoroughly insulated on non-combustible, non-absorptive insulating substance, such as porcelain.

All switches attached to the hanger-board should be so constructed that they will be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Electric Heaters should always be treated as sources of heat and kept away from inflammable materials. Each heater should have a cut-out and indicating switch, and all attachments from the feed wires to the heater should be kept in plain sight, easily accessible and protected from interference. Each heater should have a name-plate giving the maker's name and the normal capacity in volts and amperes.

Approved Apparatus and Supplies. Every article or fitting intended for use in electrical wiring or construction or in connection therewith should, before being manufactured or placed upon the market, be examined and approved by the Underwriters' National Electric Association for use under the rules and requirements of the National Board of Fire Underwriters and placed upon their official list of "approved" electrical fittings.

Any new article, therefore, or modification of an old article,

intended to be placed in general electrical use, should first be sent for examination and test to the laboratory of the Electrical Bureau of the National Board of Fire Underwriters, 67 East Twenty-first street, Chicago, Ill.

If the article is approved it will be placed upon the list of fittings, which list is revised quarterly. When buying electrical supplies of any description make sure that they have been approved. If there is any question about it, make your supply dealer give you a guarantee that they will be approved by the Fire Underwriters' Inspector if installed in accordance with the rules and requirements of the National Board of Underwriters.

Electrical Inspection. The principal points regarding the safe installation of dynamos, motors, outside and inside wiring, as required by the insurance underwriters, have been set forth in this paper. There will probably arise questions which cannot be settled by reference to the suggestions herein contained, and therefore a great deal has to be left to the judgment of the constructing engineer and inspector. In every such case the Inspection Department having jurisdiction should be consulted with perfect assurance that nothing unreasonable will ever be demanded in the way of special construction.

Every piece of wiring or electrical construction work, whether open or concealed, should be and usually is inspected, and notice, therefore, should always be sent by the contractor or engineer to the board having jurisdiction, immediately upon completion of any work.

Negligence in this matter has frequently caused floors to be torn up when doubtful work has been suspected, and at the cost of the parties who installed the wiring.

The insurance inspector cannot order any piece of wiring taken out or altered, but always reports whether or not the plant is installed in a manner which will reduce the fire risk to a minimum. If the inspector has occasion to recommend any changes which he considers for the safety of the building, and such changes are not immediately made, he recommends that the insurance rate on the building be so raised that it will, in the end, be found advisable to attend to his suggestions, which are in every case reasonable.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

GAS AND OIL ENGINES.

---

1. Describe the cycle of operations in the Lenoir engine.

2. What is the usual pressure in the cylinder when the exhaust valve opens? What device is used to reduce the work necessary to raise a valve against that pressure?

3. What is an internal combustion motor, and what are its principal advantages over the external combustion motor?

4. Describe a gas producer plant and explain the differences between the pressure and the suction types of producer plant. Will a given gas engine develop as much power with producer gas as with coal gas?

5. What is the pressure at the end of compression in the ideal Otto cycle engine with 30% clearance?

6. What is the efficiency of the engine in the previous problem, and what is the probable efficiency of an actual engine with the same clearance?

7. What is an external combustion motor and what are its principal defects?

8. Describe the series of operations of the Otto cycle.

9. Explain the hit-and-miss system of governing gas engines. How is it carried out? What are its disadvantages?

10. What are the functions of the valves used in a gas engine? What kind of valve is generally used? Which of the valves may be automatic in action?

11. Draw and explain the indicator card of an engine using the Otto cycle with increased expansion.

12. Describe the procedure in starting a small gas engine by hand. How can a large gas engine be started?

13. What is the usual method of actuating the valves? What must be the speed of revolution of the side shaft?

14. Why is it possible (a) to compress to higher pressures, and (b) to use a larger excess of air with the Diesel cycle than with the Otto cycle? How is the governing carried out in the Diesel engine?

15. Describe the method of burning heavy oils used in the Hornsby-Akroyd engine.

16. Describe the procedure in starting an engine with gasoline. How much gasoline does an average engine use per brake horse power per hour?

17. What are the most common causes of failure to start in a gas engine? How would you set to work to find out the trouble?

18. How may kerosene be vaporized before being sent to the cylinder of the engine? What is meant by the cracking of kerosene, and how is it caused?

19. What is carbureted air? Describe the action of a carburetor for gasoline. Where should the gasoline tank be placed?

20. Draw the indicator card for the Otto cycle. What kind of compression occurs in this cycle?

21. What is back-firing, how is it caused and how remedied?

22. What is the average fuel consumption in a gas engine?

23. What are the fuels used in oil engines? How are they obtained and how may they be distinguished from one another?

24. Upon what does the efficiency of the Otto cycle depend? Under what conditions will the efficiency be high?

25. Describe hot tube ignition.

26. Explain the operation of a make-and-break igniter. Sketch the necessary electric connections.

27. Explain carefully the series of operations in a two-cycle gas engine. What are the advantages and defects of this type?

28. Describe the Diesel cycle and draw an indicator card illustrating the processes.

29. Describe three methods of governing by the variable-impulse system and discuss their relative advantages.

30. What do you understand by timing the ignition, and by lead of the ignition? What is the effect of too small lead and what of too great lead? Illustrate by indicator cards.

REVIEW QUESTIONS

ON THE SUBJECT OF

AUTOMOBILES

---

1. What is the function of mufflers, and what troubles are they liable to develop?

2. Describe the methods of cylinder cooling in general use. What is the most economical temperature for the cylinders of a gasolene motor?

3. Describe the sliding gear transmission.

4. What is the difference in the action of the block, roller, and self-adjusting sprocket chains?

5 If the brake refuses to act what alternative remains to stop the machine?

6. How is the flexibility of the propeller shaft secured?

7. What forms of cooling surfaces are commonly used for air-cooled cylinders?

8. Describe the three forms of ignition.

9. Describe the steps to be taken in the operation of an automobile, and state what parts of the machine require special attention.

10. Name the three general classes of automobiles.

11. Explain the difference between 2-cycle and 4-cycle motors.

12 Describe the multiple disc clutch.

13. What is the effect on the motor of too rich gas?

14. Describe the usual method of steering an automobile.

15. How is the circulation of air maintained for air-cooling?

16. How is a sprag used?

17. Describe the white steam generator. How does it differ from an ordinary boiler?

18. What is the relative position of the clutch in the transmission system?

19. What causes premature ignition, and what is its effect?

20. What are the most common chain troubles, and how are they remedied?

21. Describe the devices used to supplement the springs of automobiles.

22. Describe four forms of friction drives.

23. What changes in automobile design are suggested by American road conditions?

24. What are the essential features of the rear axle?

25. What operations may be controlled by the steering wheel?

26. What kinds of bearings are in general use? Give the relative advantages of each kind.

27. How can the compression be tested?

28. Describe the methods used for varying the proportion of gasolene and air in different carburettors.

29. Describe the types of pumps used for water circulation.

30. Describe each of the essential parts of a gasolene motor.

31. What is the object of the differential gear, and where is it used?

32. What type of wheel is commonly used for automobiles? Describe its construction.

33. What considerations determine the location of the engine on the chassis?

34. What is the function of planetary gears, and how do they operate?

35. What is the function of radius rods, and where should they be located?

36. What is the most common form of brake for automobiles?

37. What is the most desirable method of vehicle control?

38. What is the general arrangement of the propeller shaft transmission?

39. What are the three methods of fastening pneumatic tires to the wheel rims?

REVIEW QUESTIONS

ON THE SUBJECT OF

CONSTRUCTION OF BOILERS.

1. If they are near together how are two flat parallel surfaces stayed?
2. Describe a rivet.
3. Since copper is such a desirable metal for boiler work why is it not used more extensively?
4. Why is a large factor of safety used for stays?
5. State what you can (briefly) about the injuries done to plates by punching and the methods employed to overcome them.
6. Why are not welded joints used more generally?
7. In what two ways are tubes fastened to the tube sheet?
8. About what is the ratio of length to diameter of the multitubular type of boiler?
9. Explain riveting with countersunk head.
10. Is the greatest tendency to rupture along the longitudinal or the circumferential seams?
11. Why is the length of a grate limited?
12. Which is the stronger form of riveting, the lap joint or double butt joint (both with double riveting)?
13. Why are the short screw stay bolts turned smooth in the center?
14. Why are flanged joints preferable to those made with cast iron angle irons?
15. What is the water-leg?
16. For what qualities are boiler materials tested?
17. What is the principal advantage of pneumatic calking?

18. Name some of the considerations that must be kept in mind when designing a boiler?

19. If the rivet is 1 inch in diameter what would *you* make the pitch, if single riveted lap joint?

20. Upon what does the choice of type of boiler depend?

21. What is the thickness of the shell of a boiler if the diameter is 60 inches, the steam pressure 70 pounds per square inch, the joint has an efficiency of .68 and the working strength of the metal 9000 pounds per square inch? The working strength equals the breaking strength S, divided by f.

Use the formula $t = \frac{fDp}{2SE}$. Ans. $\frac{3}{8}$ inches.

22. Find the allowable pressure, if the above conditions are the same, with the exception of t, which is $\frac{1}{2}$ inch.

Ans. 102 pounds per square inch.

23. Why should calking be done carefully and with a proper shaped tool?

24. About what fraction of the volume of a multitubular boiler is the steam space?

25. If the boiler is to supply steam to a high speed engine, should the steam space be larger or smaller than if to a low speed engine?

26. Why is wrought iron preferable to cast iron for boiler shells?

27. Why is a riveted joint weaker than an uncut plate?

28. A boiler evaporates 3211 pounds of water per hour. The grate is $6\frac{1}{2}$ feet by 4 feet and the coal evaporates $9\frac{1}{2}$ pounds of water per pound. What is the rate of combustion?

Ans. 13 pounds per sq. ft. per hour.

29. What kind of joint is generally used for longitudinal seams?

30. What should be the diameter at the top of a chimney 81 feet high if 2.88 pounds of coal are burned per horse-power per hour, and the horse-power is 160?

Use formula foot page 56. Ans. 28 inches.

31. Name four general requirements that a boiler must have.

32. What are the advantages of machine riveting

REVIEW QUESTIONS

ON THE SUBJECT OF

THE STEAM ENGINE.

PART I.

---

1. What should be the rim weight of a cast iron fly-wheel which is 15 feet in diameter, if the engine is of the Corliss type, with an 18″ × 36″ cylinder, and runs at 90 revolutions per minute?

2. In what way does the action of steam in the turbine engine differ from the action of steam in the ordinary reciprocating engine?

3. What is the theoretical height of a simple pendulum governor which makes 65 revolutions per minute?

4. In what way did Newcomen improve the steam engine?

5. Explain the difference between the condensing and the noncondensing engine, and show why the condenser increases the power of the engine.

6. Describe two methods of overcoming the danger due to high rotative speed in the steam turbine.

7. What two principles did James Watt follow in his experiments on the steam engine?

8. What types of engines have no fly-wheel? Why have they no fly-wheel?

9. What should be the thickness of rim for a cast iron fly-wheel weighing 4,480 pounds; the face is 12 inches wide, and the diameter of the wheel 15 feet?

10. Name some of Watt's inventions and improvements in the steam engine.

11. What is meant by compound and triple expansion engines?

12. What is a Woolf engine? What is a tandem engine? A cross compound?

13. Explain with sketch the action of a sight-feed cylinder lubricator.

14. What is the function of a governor?

15. Why is not the power given out by an engine constant during a given time?

16. What are the relative advantages and disadvantages of turbine engines as compared with reciprocating engines?

17. What is the office of the fly-wheel?

18. How does the height of the governor affect its sensitiveness?

19. Why are lubricants used? Name the requisites of good lubricants.

20. Name the advantages of the vertical engine.

21. Describe the two kinds of governors.

22. In what two ways do governors vary the work done on the piston?

23. How are high-speed engines oiled?

24. Which class of engine needs the larger fly-wheel, and why, high speed or low speed?

25. Describe the direct-acting steam pump.

26. How does the action of the Buckeye engine governor in changing the amount of steam admitted per stroke differ from the action of the straight-line engine governor?

27. What are the advantages and the principal disadvantages of the Corliss engine?

28. Name the requisites for high-speed reciprocating engines.

29. Why do pumping engines usually have devices for economy?

30. Explain how the expansion of steam is obtained in each of the two types of steam turbine.

31. If the height of a simple pendulum governor is 8 inches, what is the equivalent height if a weight equal to $1\frac{1}{2}$ times the weight of the balls is added?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART I.

---

1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors? Which one is preferable?

5. How can the friction of brushes and bearings be tested roughly?

6. What points should be considered in the selection of a machine?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set?

11. Why should starting boxes always be furnished with direct-current motors?

12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?

14. Describe the method of lacing a belt.

15. How are dynamotors and motor-generator sets started ?

16. What precaution should be taken when starting a new machine for the first time.

17. Immediately after stopping a machine what should be done to it ?

18. What advantages have circuit breakers over fuses ?

19. What are the objections to series motor for single-phase circuits ?

20. What is an enclosed fuse, and in what way is it better than a link fuse ?

21. Give a sketch of the wiring for a three-phase Y system for both light and power distribution.

22. Explain the principle and use of a starting compensator.

23. What advantage does rope driving possess over ordinary belting ?

24. When synchronizing two alternators should the switch be closed when the two machines are approaching synchronism, or when they are receding from it.

25. How can sparking at the commutator be measured roughly ?

26. In placing a knife switch should it be so located that gravity tends to open it or to close it ?

27. Describe with sketch the connections for two compound-wound dynamos in parallel.

28. How would you test a machine for balance ?

29. Describe with sketch the connections for a typical single-phase installation.

30. What points must be considered if two alternators are to be run in parallel ?

31. Describe with sketch the method of synchronizing on a three-phase system.

32. Should the loose side of a belt be on the top or below ? Explain why.

33. Give a sketch of two generators connected on the three-wire system.

34. Why is a series motor particularly adapted for railway work ?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II.

---

1. In measuring resistance with the Wheatstone bridge, what is the objection of using a ratio of 1000 : 1 or 100 : 1?

2. Describe a tachometer. What advantage has this over the speed counter?

3. What is the torque of a 20 horse-power motor running at the rate of 600 r.p.m.?

4. When the armature of a machine becomes overheated and the belt is tight on the tension side, to what would you ascribe the cause and how would you remedy it?

5. Explain how to true up the commutator in case it becomes rough or uneven.

6. Describe a method of testing to see if the armature is centered between the pole pieces.

7. What is the pull in pounds in the case of a 40 horse-power motor if the speed is 550 r.p.m. and the pulley is 3 feet in diameter?

8. What do you understand to be meant by a ground in the armature?

9. If the speed of a generator is too high, what effect does this have on the voltage?

10. Describe with formula the direct-deflection method of measuring insulation resistance.

11. Describe a method of determining the current in a circuit if you have a voltmeter but no ammeter at hand.

12. How does eddy-current loss vary with the speed?

13. Explain briefly the method of separating the eddy current loss from the hysteresis loss in a generator.

14. How does an eccentric commutator manifest itself?

15. If the residual magnetism of a dynamo be weak or entirely destroyed, how would you explain the cause for the same? How would such trouble manifest itself, and what is the remedy?

16. What resistance does a Weston voltmeter usually have?

17. Supposing the commutator of a machine is covered with a dark coating, while the commutator brushes and brush holders show marks of abnormal heat, what is likely to be the cause and what remedy should be applied?

18. Name the causes of the voltage of a generator being too low.

19. What difficulty would arise in attempting to measure the armature resistance of a 20 horse-power 110-volt shunt machine with the Wheatstone bridge?

20. In testing the output of a large generator, how would you dispose of the large current generated? Give two methods.

21. What is meant by the efficiency of a generator?

22. Which is preferable to use on a commutator, sand paper or emery?

23. Which is preferable, that the commutator should have a bright, clean appearance, or be covered with a brown glaze or polish?

24. How can Foucault currents in the pole pieces or field cores be detected? What usually gives rise to such action?

25. What is the advantage of over-compounding so that a machine gives a higher voltage at full load than at low load?

26. A motor which is running without load is found to take excessive current, give a cause and remedy for the same.

27. If the field coils of the machine are too hot as determined by testing with the hand, what remedy would you apply?

28. Why cannot insulation resistance be measured by means of the Wheatstone bridge?

29. How could you determine the speed of a belted machine without the use of any sort of a speed indicator?

30. What is meant by the efficiency of a motor?

31. How does hysteretic loss vary with the speed?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC WIRING.

---

1. Under what conditions is "fishing" of wires allowed? Explain the process.

2. In conduit work how many quarter bends are allowed from outlet to outlet?

3. Tell what you can about flexible cord.

4. Where should cut-outs or circuit breakers be located for house wiring?

5. What must be the voltage of the dynamo in order to supply lamps or motors in a 110-volt system, with a 5 per cent loss?

6. What is a cull pole?

7. When a high-potential machine has its frame grounded, what precautions should be taken for the protection of the attendant?

8. What can you say about the rules to be followed when installing wires?

9. Give a rule for the proper depth to which to set a pole.

10. How would you ground a dynamo frame?

11. What is the least allowable radius of curvature in conduit work?

12. State the rule to be followed in starting or stopping motors.

13. What is the objection to putting the ground wire from a lightning arrester into an iron pipe?

14. State briefly the requirements for interior wiring in the case of series arc lighting work.

15. Describe the care which should be given to the brushes to keep them in good condition.

16. Describe a piece of apparatus for protecting the armature of a motor.

17. Why should standard rubber-covered wires be used in conduit work?

18. What is the least space that should be left between

(a) The switchboard and the floor?

(b) The switchboard and the ceiling?

19. What is the largest permissible current dependent upon one cut-out?

20. What insulation resistance is required between gas pipe attachments and an insulating joint?

21. Under what conditions should the frame of a dynamo be grounded?

22. What kind of wire must be used in moulding work?

23. What can you say about wiring for damp places?

24. In which direction does the armature of a generator usually revolve?

25. Determine by use of table on page 40 what size of wire should be used to supply 75 16-candle-power incandescent lights, 110 volts, loss 3 volts, and at a distance of 200 feet to center of distribution.

26. What is the best material for poles?

27. Describe a method of setting the brushes so that they will be diametrically opposite each other.

28. In splicing two pieces of wire, what precautions are necessary?

29. What size of wire will be required to supply a 10-horse-power motor on a 500-volt circuit at a distance of 200 feet with 15 volts' drop?

30. What current is taken by the motor referred to in Question 29?

31. Describe the connections for the three-wire system.

32. Determine by formula the size of wire for 40 16-candle-power incandescent lights on a 110-volt circuit with 5 volts' drop at a distance of 150 feet.